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(54) Title of Invention

Secondary Battery

(57) Abstract

The present invention provides a secondary battery, which includes a positive electrode plate, a negative electrode plate, an electrolyte, and a separator. The positive electrode plate includes a positive electrode current collector and a positive electrode film that is disposed on at least one surface of the positive electrode current collector and includes a positive electrode active material; the negative electrode plate includes a negative electrode current collector and a negative electrode film that is disposed on at least one surface of the negative electrode current collector and includes a negative electrode active material. The secondary battery further satisfies $0.1 \leq (D50_N \times M_N) / [(D50_P + 4) \times (M_P + 4)] \leq 1.5$. By properly matching the relationship between the particle sizes of the positive and negative electrode active materials and the capacities of the positive and negative electrode films, the present invention obtains a secondary battery that combines long cycle life, high energy density, and fast charge and discharge capability.

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1. A secondary battery, comprising a positive electrode plate, a negative electrode plate, an electrolyte, and a separator, the positive electrode plate comprising a positive electrode current collector and a positive electrode film that is disposed on at least one surface of the positive electrode current collector and comprises a positive electrode active material, and the negative electrode plate comprising a negative electrode current collector and a negative electrode film that is disposed on at least one surface of the negative electrode current collector and comprises a negative electrode active material;

characterized in that,

the secondary battery satisfies: $0.1 \leq (D50_N \times M_N) / [(D50_P + 4) \times (M_P + 4)] \leq 1.5$;

wherein,

$D50_P$ is the particle size of the positive electrode active material at which the cumulative volume percentage reaches 50%, expressed in μm ;

$D50_N$ is the particle size of the negative electrode active material at which the cumulative volume percentage reaches 50%, expressed in μm ;

M_P is the capacity per unit area of the positive electrode film, expressed in mAh/cm^2 ; and

M_N is the capacity per unit area of the negative electrode film, expressed in mAh/cm^2 .

2. The secondary battery according to claim 1, characterized in that,

the secondary battery satisfies: $0.2 \leq (D50_N \times M_N) / [(D50_P + 4) \times (M_P + 4)] \leq 1.0$;

preferably, the secondary battery satisfies: $0.3 \leq (D50_N \times M_N) / [(D50_P + 4) \times (M_P + 4)] \leq 0.7$.

3. The secondary battery according to claim 1 or 2, characterized in that,

the secondary battery satisfies: $35 \leq (D50_P + 4) \times (M_P + 4) \leq 230$;

preferably, the secondary battery satisfies: $60 \leq (D50_P + 4) \times (M_P + 4) \leq 150$.

4. The secondary battery according to claim 1 or 2, characterized in that the particle size $D50_P$ of the positive electrode active material is $0.2 \mu\text{m}$ to $25 \mu\text{m}$, preferably $0.4 \mu\text{m}$ to $15 \mu\text{m}$.

5. The secondary battery according to claim 1 or 2, characterized in that the capacity per unit area M_P of the positive electrode film is $1 \text{mAh}/\text{cm}^2$ to $10 \text{mAh}/\text{cm}^2$, preferably $2 \text{mAh}/\text{cm}^2$ to $6 \text{mAh}/\text{cm}^2$.

6. The secondary battery according to claim 1 or 2, characterized in that,

the secondary battery satisfies: $1 \leq D50_N \times M_N \leq 100$;

preferably, the secondary battery satisfies: $10 \leq D50_N \times M_N \leq 80$.

7. The secondary battery according to claim 1 or 2, characterized in that the particle size $D50_N$ of the negative electrode active material is $0.4 \mu\text{m}$ to $30 \mu\text{m}$, preferably $0.5 \mu\text{m}$ to $16 \mu\text{m}$.

8. The secondary battery according to claim 1 or 2, characterized in that the capacity per unit area M_N of the negative electrode film is $1 \text{mAh}/\text{cm}^2$ to $10 \text{mAh}/\text{cm}^2$, preferably $2 \text{mAh}/\text{cm}^2$ to $7 \text{mAh}/\text{cm}^2$.

9. The secondary battery according to claim 1, characterized in that the positive electrode active material is selected from one or more of lithium cobalt oxide, lithium nickel oxide, lithium manganese oxide, lithium nickel manganese oxide, lithium nickel cobalt manganese oxide, lithium nickel cobalt aluminum oxide, and olivine-structured lithium-containing phosphates.

10. The secondary battery according to claim 1, characterized in that

the negative electrode active material is selected from one or more of carbon materials, silicon-based materials, tin-based materials, and lithium titanate;

preferably, the negative electrode active material is selected from one or more of carbon materials and silicon-based materials.

Secondary Battery

Technical Field

[0001] The present invention relates to the field of batteries, and in particular to a secondary battery.

Background Art

[0002] Rechargeable batteries have outstanding features such as light weight, high energy density, no pollution, absence of memory effect, and long service life, and are therefore widely used in fields such as mobile phones, computers, household appliances, and power tools. Charging time, meanwhile, is receiving increasing attention from end consumers and is an important factor limiting the wider adoption of rechargeable batteries. In terms of technical principle, the key factor determining the charging speed of a rechargeable battery is the negative electrode.

[0003] In addition, for a rechargeable battery, the magnitude of its output power, that is, the fast discharge capability of the battery, is also an important factor limiting the rapid adoption of rechargeable batteries. In terms of technical principle, the key factor determining the output power of a rechargeable battery is the positive electrode.

[0004] The matching of the kinetic performance of the positive electrode plate and the negative electrode plate therefore has a critical influence on a rechargeable battery.

Summary of the Invention

[0005] In view of the problems existing in the background art, an object of the present invention is to provide a secondary battery that combines long cycle life, high energy density, and fast charge and discharge capability.

[0006] To achieve the above object, the present invention provides a secondary battery, which includes a positive electrode plate, a negative electrode plate, an electrolyte, and a separator. The positive electrode plate includes a positive electrode current collector and a positive electrode film that is disposed on at least one surface of the positive electrode current collector and includes a positive electrode active material; the negative electrode plate includes a negative electrode current collector and a negative electrode film that is disposed on at least one surface of the negative electrode current collector and includes a negative electrode active material. The secondary battery further satisfies: $0.1 \leq (D50_N \times M_N) / [(D50_P + 4) \times (M_P + 4)] \leq 1.5$, where $D50_P$ is the particle size of the positive electrode active material at which the cumulative volume percentage reaches 50%, expressed in μm ; $D50_N$ is the particle size of the negative electrode active material at which the cumulative volume percentage reaches 50%, expressed in μm ; M_P is the capacity per unit area of the positive electrode film, expressed in mAh/cm^2 ; and M_N is the capacity per unit area of the negative electrode film, expressed in mAh/cm^2 .

[0007] Compared with the prior art, the present invention includes at least the following beneficial effects: by properly matching the relationship between the particle sizes of the positive and negative electrode active materials and the capacities of the positive and negative electrode films, the present invention obtains a secondary battery that combines long cycle life, high energy density, and fast charge and discharge capability.

Detailed Description

[0008] The secondary battery according to the present invention is described in detail below.

[0009] The secondary battery of the present invention includes a positive electrode plate, a negative electrode plate, an electrolyte, and a separator. The positive electrode plate includes a positive electrode current collector and a positive electrode film that is disposed on at least one surface of the positive electrode current collector and includes a positive electrode active material; the negative electrode plate includes a negative electrode current collector and a negative electrode film that is disposed on at least one surface of the negative electrode current collector and includes a negative electrode active material.

[0010] The secondary battery of the present invention further satisfies: $0.1 \leq (D50_N \times M_N) / [(D50_P + 4) \times (M_P + 4)] \leq 1.5$, where $D50_P$ is the particle size of the positive electrode active material at which the cumulative volume percentage reaches 50%, expressed in μm ; $D50_N$ is the particle size of the negative electrode active material at which the cumulative volume percentage reaches 50%, expressed in μm ; M_P is the capacity per unit area of the positive electrode film,

expressed in mAh/cm²; and M_N is the capacity per unit area of the negative electrode film, expressed in mAh/cm².

[0011] Generally, in the design of a secondary battery, if the kinetic performance of the positive electrode plate is far superior to that of the negative electrode plate, the negative electrode will be charged to a very low potential at a high SOC during fast charging of the battery, the negative electrode potential will reach 0 V prematurely, and active ions will then be reduced and deposited directly on the surface of the negative electrode. If the kinetic performance of the negative electrode plate is far superior to that of the positive electrode plate, the positive electrode will be discharged to a very high potential at a high SOC during fast discharging of the battery, while the positive electrode plate cannot instantaneously accept a large quantity of active ions; this gives rise to pronounced polarization, the battery reaches the cut-off voltage prematurely, and the capacity of the battery cannot be fully delivered. Moreover, over long-term cycling of the battery, the structure of the positive electrode active material suffers considerable damage, and the cycle life of the battery is impaired as a result.

[0012] Through extensive research, the inventors have found that when a secondary battery satisfies $0.1 \leq (D50_N \times M_N) / [(D50_P + 4) \times (M_P + 4)] \leq 1.5$, the kinetic performance of the positive electrode plate and that of the negative electrode plate can be well matched, and the resulting secondary battery combines long cycle life, high energy density, and fast charge and discharge capability.

[0013] In the positive electrode plate, the larger the particle size $D50_P$ of the positive electrode active material, the poorer the kinetic performance of the positive electrode plate generally is under the same conditions; the larger the capacity per unit area M_P of the positive electrode film, the higher the energy density of the secondary battery, but the poorer the kinetic performance.

[0014] Similarly, in the negative electrode plate, the larger the particle size $D50_N$ of the negative electrode active material, the poorer the kinetic performance of the negative electrode plate generally is under the same conditions; the larger the capacity per unit area M_N of the negative electrode film, the poorer the kinetic performance of the negative electrode plate.

[0015] Through extensive research, the inventors have found that when $0.1 \leq (D50_N \times M_N) / [(D50_P + 4) \times (M_P + 4)] \leq 1.5$, the charge and discharge capabilities of the positive electrode plate and the negative electrode plate are properly matched, and the battery can simultaneously combine long cycle life, high energy density, and fast charge and discharge capability. If $(D50_N \times M_N) / [(D50_P + 4) \times (M_P + 4)]$ is greater than 1.5, this indicates that the kinetic performance of the positive electrode plate is far superior to that of the negative electrode plate; during fast charging, the negative electrode will be charged to a very low potential at a high SOC, the negative electrode potential will reach 0 V prematurely, and active ions will then be reduced and deposited directly on the surface of the negative electrode. If $(D50_N \times M_N) / [(D50_P + 4) \times (M_P + 4)]$ is less than 0.1, this indicates that the kinetic performance of the negative electrode plate is far superior to that of the positive electrode plate; during fast discharging, the positive electrode will be discharged to a very high potential at a high SOC, while the positive electrode plate cannot instantaneously accept a large quantity of active ions, giving rise to pronounced polarization; the battery reaches the cut-off voltage prematurely and its capacity cannot be fully delivered; moreover, over long-term cycling of the battery, the structure of the positive electrode active material suffers considerable damage, and the cycle life of the battery is impaired as a result.

[0016] In some embodiments of the present invention, the lower limit of $(D50_N \times M_N) / [(D50_P + 4) \times (M_P + 4)]$ may be 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, or 0.8, and the upper limit of $(D50_N \times M_N) / [(D50_P + 4) \times (M_P + 4)]$ may be 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, or 1.5.

[0017] Preferably, $0.2 \leq (D50_N \times M_N) / [(D50_P + 4) \times (M_P + 4)] \leq 1.0$; more preferably, $0.3 \leq (D50_N \times M_N) / [(D50_P + 4) \times (M_P + 4)] \leq 0.7$.

[0018] In the secondary battery of the present invention, preferably, $35 \leq (D50_P + 4) \times (M_P + 4) \leq 230$, where the lower limit of $(D50_P + 4) \times (M_P + 4)$ may be 35, 40, 45, 50, 55, 60, 65, 70, 75, or 80, and the upper limit of $(D50_P + 4) \times (M_P + 4)$ may be 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 210, 220, or 230. More preferably, $60 \leq (D50_P + 4) \times (M_P + 4) \leq 150$. Within the preferred ranges, the positive electrode plate can combine good kinetic performance with high volumetric energy density.

[0019] In the secondary battery of the present invention, preferably, the particle size $D50_P$ of the positive electrode active material is 0.2 μm to 25 μm ; more preferably, the particle size $D50_P$ of the positive electrode active material is 0.4 μm to 15 μm . Within the preferred ranges, the positive electrode plate can have better kinetic performance, which is more conducive to improving the fast discharge capability and cycle life of the secondary battery.

[0020] In the secondary battery of the present invention, preferably, the capacity per unit area M_P of the positive electrode film is 1 mAh/cm^2 to 10 mAh/cm^2 ; more preferably, the capacity per unit area M_P of the positive electrode film is 2 mAh/cm^2 to 6 mAh/cm^2 . Within the preferred ranges, the positive electrode plate can have better kinetic performance, which is more conducive to improving the fast discharge capability and energy density of the secondary battery.

[0021] In the secondary battery of the present invention, preferably, $1 \leq D_{50N} \times M_N \leq 100$, where the lower limit of $D_{50N} \times M_N$ can be 1, 2, 4, 6, 8, 10, 12, 14, 16, 18, or 20, and the upper limit of $D_{50N} \times M_N$ can be 18, 20, 22, 24, 30, 35, 40, 45, 50, 60, 70, 80, 90, or 100. More preferably, $10 \leq D_{50N} \times M_N \leq 80$. Within the preferred ranges, the negative electrode plate can combine good kinetic performance with high volumetric energy density.

[0022] In the secondary battery of the present invention, preferably, the particle size D_{50N} of the negative electrode active material is $0.4 \text{ }\mu\text{m}$ to $30 \text{ }\mu\text{m}$; more preferably, the particle size D_{50N} of the negative electrode active material is $0.5 \text{ }\mu\text{m}$ to $16 \text{ }\mu\text{m}$. Within the preferred ranges, the negative electrode plate can have better kinetic performance, which is more conducive to improving the fast charge capability and cycle life of the secondary battery.

[0023] In the secondary battery of the present invention, preferably, the capacity per unit area M_N of the negative electrode film is 1 mAh/cm^2 to 10 mAh/cm^2 ; more preferably, the capacity per unit area M_N of the negative electrode film is 2 mAh/cm^2 to 7 mAh/cm^2 . Within the preferred ranges, the negative electrode plate can have better kinetic performance, which is more conducive to improving the fast charge capability and energy density of the secondary battery.

[0024] In the secondary battery of the present invention, the positive electrode film may be disposed on one surface of the positive electrode current collector or on both surfaces of the positive electrode current collector. The positive electrode film may further include a conductive agent and a binder; the types and contents of the conductive agent and the binder are not specifically limited and may be selected according to actual requirements. The type of the positive electrode current collector is likewise not specifically limited and may be selected according to actual requirements.

[0025] In the secondary battery of the present invention, the negative electrode film may be disposed on one surface of the negative electrode current collector or on both surfaces of the negative electrode current collector. The negative electrode film may further include a conductive agent and a binder; the types and contents of the conductive agent and the binder are not specifically limited and may be selected according to actual requirements. The type of the negative electrode current collector is likewise not specifically limited and may be selected according to actual requirements.

[0026] It should be noted that, when positive and negative electrode films are disposed on both surfaces of the positive and negative electrode current collectors respectively, the battery is considered to fall within the protection scope of the present invention as long as the positive electrode film on any one surface of the positive electrode current collector and the negative electrode film on any one surface of the negative electrode current collector satisfy $0.1 \leq (D_{50N} \times M_N) / [(D_{50P} + 4) \times (M_P + 4)] \leq 1.5$. In addition, the positive and negative electrode film parameters given in the present invention all refer to the parameters of single-sided positive and negative electrode films.

[0027] In the secondary battery of the present invention, the specific type of the positive electrode active material is not specifically limited and may be selected according to actual requirements. Preferably, the positive electrode active material may be selected from one or more of lithium cobalt oxide, lithium nickel oxide, lithium manganese oxide, lithium nickel manganese oxide, lithium nickel cobalt manganese oxide, lithium nickel cobalt aluminum oxide, and olivine-structured lithium-containing phosphates. More preferably, the positive electrode active material may specifically be selected from one or more of LiCoO_2 , LiNiO_2 , LiMnO_2 , LiMn_2O_4 , $\text{LiNi}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}\text{O}_2$ (NCM333), $\text{LiNi}_{0.5}\text{Co}_{0.2}\text{Mn}_{0.3}\text{O}_2$ (NCM523), $\text{LiNi}_{0.6}\text{Co}_{0.2}\text{Mn}_{0.2}\text{O}_2$ (NCM622), $\text{LiNi}_{0.8}\text{Co}_{0.1}\text{Mn}_{0.1}\text{O}_2$ (NCM811), $\text{LiNi}_{0.85}\text{Co}_{0.15}\text{Al}_{0.05}\text{O}_2$, LiFePO_4 (LFP), and LiMnPO_4 .

[0028] In the secondary battery of the present invention, the specific type of the negative electrode active material is not specifically limited and may be selected according to actual requirements. Preferably, the negative electrode active material may be selected from one or more of carbon materials, silicon-based materials, tin-based materials, and lithium titanate. The carbon materials may be selected from one or more of graphite, soft carbon, hard carbon, carbon fiber, and mesocarbon microbeads; the graphite may be selected from one or more of artificial graphite and natural graphite; the silicon-based materials may be selected from one or more of elemental silicon, silicon-oxygen compounds, silicon-carbon composites, and silicon alloys; and the tin-based materials may be selected from one or more of elemental tin,

tin-oxygen compounds, and tin alloys. More preferably, the negative electrode active material is selected from one or more of carbon materials and silicon-based materials.

[0029] In the secondary battery of the present invention, the separator is disposed between the positive electrode plate and the negative electrode plate to provide isolation. The type of the separator is not specifically limited; it may be any separator material used in existing batteries, for example, polyethylene, polypropylene, polyvinylidene fluoride, and multilayer composite films thereof, but is not limited to these.

[0030] In the secondary battery of the present invention, the type of the electrolyte is not specifically limited; it may be a liquid electrolyte (also referred to as an electrolytic solution) or a solid electrolyte. Preferably, a liquid electrolyte is used as the electrolyte. The liquid electrolyte may include an electrolyte salt and an organic solvent; the specific types of the electrolyte salt and the organic solvent are not specifically limited and may be selected according to actual requirements. The electrolyte may further include an additive; the type of the additive is not particularly limited either, and it may be a negative electrode film-forming additive, a positive electrode film-forming additive, or an additive capable of improving certain performance aspects of the battery, for example, an additive that improves the overcharge performance of the battery, an additive that improves the high-temperature performance of the battery, an additive that improves the low-temperature performance of the battery, and the like.

[0031] The present application is further illustrated below, taking a lithium-ion battery as an example and in conjunction with specific examples. It should be understood that these examples are intended only to illustrate the present application and not to limit its scope.

[0032] Example 1

[0033] (1) Preparation of the positive electrode plate

[0034] The positive electrode active material (see Table 1 for details), the conductive agent Super P, and the binder polyvinylidene fluoride (PVDF) were mixed at a mass ratio of 96:2:2; the solvent N-methylpyrrolidone (NMP) was added, and the mixture was stirred in a vacuum mixer until the system was homogeneous, giving a positive electrode slurry. The positive electrode slurry was coated uniformly onto an aluminum-foil positive electrode current collector; the positive electrode current collector coated with the slurry was air-dried at room temperature, transferred to an oven for further drying, and then cold-pressed and slit to give the positive electrode plate.

[0035] (2) Preparation of the negative electrode plate

[0036] The negative electrode active material (see Table 1 for details), the conductive agent Super P, the thickener sodium carboxymethyl cellulose (CMC), and the binder styrene-butadiene rubber (SBR) were mixed at a mass ratio of 94.5:1.5:1.5:2.5; the solvent deionized water was added, and the mixture was stirred in a vacuum mixer until the system was homogeneous, giving a negative electrode slurry. The negative electrode slurry was coated uniformly onto a copper-foil negative electrode current collector; the negative electrode current collector coated with the slurry was air-dried at room temperature, transferred to an oven for further drying, and then cold-pressed and slit to give the negative electrode plate.

[0037] (3) Preparation of the electrolytic solution

[0038] Ethylene carbonate (EC), dimethyl carbonate (DMC), and diethyl carbonate (DEC) were mixed at a volume ratio of 1:1:1 to give an organic solvent; the fully dried lithium salt LiPF_6 was then dissolved in the mixed organic solvent to prepare an electrolytic solution with a concentration of 1 mol/L.

[0039] (4) Preparation of the separator

[0040] A polyethylene film was used as the separator.

[0041] (5) Preparation of the lithium-ion battery

[0042] The positive electrode plate, the separator, and the negative electrode plate prepared above were stacked in order, with the separator positioned between the positive and negative electrode plates to provide isolation, and then wound to give a bare cell. The bare cell was placed in an outer packaging case, dried, and injected with the electrolytic solution; the lithium-ion battery was obtained after processes such as vacuum packaging, standing, formation, and shaping.

[0043] The lithium-ion batteries of Examples 2 to 16 and Comparative Examples 1 to 6 were each prepared by a method similar to that of Example 1; the specific differences are shown in Table 1.

[0044] Table 1: Parameters of Examples 1-16 and Comparative Examples 1-6

[0045]

	Positive electrode plate				Negative electrode plate				C= B/A
	Positive electrode active material	D50 μm	Capacity M (mAh/cm ²)	A = (D50 + 4) $\times$ (M + 4)	Negative electrode active material	D50 μm	Capacity M (mAh/cm ²)	B=D 50 $\times$ M	
Example 1	LFP	15.2	8.0	230	Graphite	2.3	10.0	23	0.10
Example 2	LFP	13.5	7.5	201	Graphite	4.4	9.0	40	0.20
Example 3	LFP	8.0	7.0	132	Graphite	4.4	9.0	40	0.30
Example 4	LFP	4.0	6.0	80	Graphite	5.0	8.0	40	0.50
Example 5	LFP	3.9	5.0	71	Graphite	7.1	7.0	50	0.70
Example 6	LFP	3.5	4.0	60	Graphite	10.0	6.0	60	1.00
Example 7	LFP	2.5	2.2	40	Graphite	16.0	3.7	59	1.47
Example 8	LFP	0.3	3.0	30	Graphite	3.6	5.0	18	0.60
Example 9	LFP	1.0	2.0	30	Graphite	4.5	4.0	18	0.60
Example 10	LFP	2.1	1.5	33	Graphite	6.7	3.0	20	0.60
Example 11	LFP	2.4	1.2	33	Graphite	10.0	2.0	20	0.60
Example 12	LFP	2.7	1.0	33	Graphite	13.3	1.5	20	0.60
Example 13	LFP	29.8	2.5	220	Hard carbon	5.5	4.0	22	0.10
Example 14	LFP	4.3	0.8	40	Hard carbon	20.0	3.0	60	1.50
Example 15	NCM 811	29.8	2.5	220	Mixture of graphite and silicon monoxide at a mass ratio of 8:2	5.5	4.0	22	0.10
Example 16	NCM 811	4.3	0.8	40	Mixture of graphite and silicon monoxide at a mass ratio of 8:2	20.0	3.0	60	1.50
Comparative Example 1	LFP	26.8	2.5	200	Graphite	2.5	4.0	10	0.05
Comparative Example 2	LFP	1.3	1.0	27	Graphite	21.3	2.0	43	1.60
Comparative Example 3	LFP	22.3	3.6	200	Hard carbon	2.5	4.0	10	0.05
Comparative Example 4	LFP	1.3	1.0	27	Hard carbon	21.3	2.0	43	1.60
Comparative Example 5	NCM 811	22.3	3.6	200	Mixture of graphite and silicon monoxide at a mass ratio of 8:2	2.5	4.0	10	0.05
Comparative Example 6	NCM 811	1.3	1.0	27	Mixture of graphite and silicon monoxide at a mass ratio of 8:2	21.3	2.0	43	1.60

[0046] The testing process and test results of the lithium-ion batteries are described next.

[0047] 1. Electrode plate testing

[0048] (1) Particle size testing of the positive and negative electrode active materials

[0049] The particle sizes of the positive and negative electrode active materials may be obtained by measurement using a laser diffraction particle size distribution analyzer (Mastersizer 3000).

[0050] (2) Testing of the capacity per unit area of the positive electrode film

[0051] Step 1): The lithium-ion battery containing the positive electrode plate of each example or comparative example was fully discharged and left to stand for 5 minutes, and was then charged to the cut-off voltage; specifically, the battery was charged at a constant current of $1/3C$ to the cut-off voltage and then charged at constant voltage at the cut-off voltage until the current reached $0.03C$. The charge capacity C_0 obtained at this point is the discharge capacity of the positive electrode film.

[0052] Step 2): The total area of the positive electrode film was measured and calculated (the total area here refers to the coated area; in the case of double-sided coating, the coated areas of the two sides are added together).

[0053] Step 3): The capacity per unit area of the positive electrode film was calculated according to: capacity per unit area of the positive electrode film = discharge capacity of the positive electrode film (mAh)/total area of the positive electrode film (cm^2).

[0054] (3) Testing of the capacity per unit area of the negative electrode film:

[0055] Step 1): The negative electrode plates of the above examples and comparative examples were taken, and small single-side-coated negative electrode discs of a given area were obtained using a punching die. Six CR2430 coin cells were assembled in an argon-protected glovebox, using a lithium metal sheet as the counter electrode, a Celgard film as the separator, and a solution of LiPF_6 (at a concentration of 1 mol/L) dissolved in EC + DMC + DEC (at a volume ratio of 1:1:1) as the electrolytic solution. After assembly, the coin cells were left to stand for 12 h and then discharged at a constant current of $0.05C$ to a voltage of 5 mV, then discharged at a constant current of 50 μA to a voltage of 5 mV, then discharged at a constant current of 10 μA to a voltage of 5 mV, and left to stand for 5 minutes; finally, the cells were charged at a constant current of $0.05C$ to a final voltage of 2 V, and the charge capacity was recorded. The average of the charge capacities of the six coin cells is the average charge capacity of the negative electrode film.

[0056] Step 2): The diameter d of the negative electrode discs was measured using a caliper, and the area of the negative electrode discs was calculated.

[0057] Step 3): The capacity per unit area of the negative electrode film was calculated according to: capacity per unit area of the negative electrode film = average charge capacity of the negative electrode film (mAh)/area of the negative electrode disc (cm^2).

[0058] 2. Lithium-ion battery performance testing

[0059] (1) Charge performance test:

[0060] At 25°C , the lithium-ion batteries prepared in the examples and comparative examples were fully charged at xC and fully discharged at $1C$, repeated 10 times; each battery was then fully charged at xC , after which the negative electrode plate was removed by disassembly and the surface of the negative electrode plate was examined for lithium plating. If no lithium plating was observed on the negative electrode surface, the test was repeated with the charge rate xC increased in increments of $0.1C$ until lithium plating occurred on the negative electrode surface, at which point testing was stopped; the charge rate xC at that point minus $0.1C$ is the maximum charge rate of the lithium-ion battery.

[0061] (2) Discharge performance test:

[0062] At 25°C , the lithium-ion batteries prepared in the examples and comparative examples were fully charged at $1C$ and then discharged at $1C$ and at $4C$ respectively, and the ratio of the $4C$ discharge capacity to the $1C$ discharge capacity was determined. A ratio of greater than or equal to 95% indicates excellent discharge performance of the lithium-ion battery; a ratio between 85% and 95% indicates moderate discharge performance; and a ratio of less than or equal to 85% indicates poor discharge performance.

[0063] (3) Cycle life test:

[0064] At 25°C , the lithium-ion batteries prepared in the examples and comparative examples were subjected to full charge/discharge cycling at a $3C$ charge rate and a $1C$ discharge rate until the capacity of the lithium-ion battery fell below 80% of the initial capacity, and the number of cycles was recorded.

[0065] (4) Actual energy density test:

[0066] At 25°C , the lithium-ion batteries prepared in the examples and comparative examples were fully charged at $1C$ and fully discharged at $1C$, and the actual discharge energy at this point was recorded. At 25°C , the lithium-ion battery was weighed on an electronic balance; the ratio of the actual $1C$ discharge energy of the lithium-ion battery to the weight of the lithium-ion battery is the actual energy density of the lithium-ion battery.

[0067] When the actual energy density is less than 80% of the target energy density, the actual energy density of

the battery is considered very low; when the actual energy density is greater than or equal to 80% of the target energy density but less than 95% of the target energy density, the actual energy density of the battery is considered relatively low; when the actual energy density is greater than or equal to 95% of the target energy density but less than 105% of the target energy density, the actual energy density of the battery is considered moderate; when the actual energy density is greater than or equal to 105% of the target energy density but less than 120% of the target energy density, the actual energy density of the battery is considered relatively high; and when the actual energy density is 120% of the target energy density or more, the actual energy density of the battery is considered very high.

[0068] Table 2: Test results of Examples 1-16 and Comparative Examples 1-6

[0069]

	Maximum charge rate	Discharge performance	Number of cycles	Actual energy density
Example 1	4.0C	Moderate	3520	Very high
Example 2	3.6C	Moderate	4200	Very high
Example 3	3.6C	Moderate	4350	Very high
Example 4	3.6C	Moderate	4500	Very high
Example 5	3.3C	Moderate	4600	Very high
Example 6	3.6C	Moderate	3680	Very high
Example 7	3.0C	Moderate	3000	Relatively high
Example 8	3.6C	Excellent	3400	Very high
Example 9	3.3C	Excellent	3300	Very high
Example 10	3.2C	Excellent	3000	Relatively high
Example 11	3.2C	Excellent	3100	Moderate
Example 12	3.0C	Excellent	2800	Moderate
Example 13	4.0C	Moderate	4000	Very high
Example 14	3.0C	Excellent	2000	Moderate
Example 15	4.0C	Moderate	1800	Very high
Example 16	3.0C	Excellent	1400	Moderate
Comparative Example 1	5.0C	Poor	1800	Relatively high
Comparative Example 2	1.0C	Excellent	150	Moderate
Comparative Example 3	5.0C	Poor	2700	Relatively high
Comparative Example 4	1.0C	Excellent	300	Moderate
Comparative Example 5	4.5C	Poor	1700	Relatively high
Comparative Example 6	1.0C	Excellent	200	Moderate

[0070] It can be seen from the test results in Table 2 that the batteries of Examples 1-16 combine long cycle life, high energy density, and fast charge and discharge capability. This is because the batteries of Examples 1-16 all satisfy $0.1 \leq (D50_{N \times M_N}) / [(D50_{P+4}) \times (M_{P+4})] \leq 1.5$; under this condition, the kinetic performance of the positive electrode plate and that of the negative electrode plate can be well matched, and the resulting batteries therefore combine long cycle life, high energy density, and fast charge and discharge capability.

[0071] In Comparative Examples 1-6, the kinetic balance ratio between the negative electrode plate and the positive electrode plate is mismatched, with $(D50_{N \times M_N}) / [(D50_{P+4}) \times (M_{P+4})]$ falling outside the given range in every case; the batteries therefore cannot readily combine long cycle life, high energy density, and fast charge and discharge capability.

[0072] It can be seen from Examples 13-16 and Comparative Examples 3-6 that, when different positive and negative electrode active materials are used in the battery, the resulting battery combines long cycle life, high energy

density, and fast charge and discharge capability as long as $0.1 \leq (D50_N \times M_N) / [(D50_P + 4) \times (M_P + 4)] \leq 1.5$ is satisfied.

[0073] Further, the positive electrode plate preferably satisfies $35 \leq (D50_P + 4) \times (M_P + 4) \leq 230$, and the negative electrode plate preferably satisfies $1 \leq D50_N \times M_N \leq 100$; within these preferred ranges, the positive electrode plate and the negative electrode plate can each maintain better kinetic performance, which is more conducive to improving the cycle life, energy density, fast charge capability, and fast discharge capability of the battery. However, even when one or both of the parameters $(D50_P + 4) \times (M_P + 4)$ and $D50_N \times M_N$ fail to meet these requirements, as long as $0.1 \leq (D50_N \times M_N) / [(D50_P + 4) \times (M_P + 4)] \leq 1.5$ is ensured, the battery can still combine long cycle life, high energy density, and fast charge and discharge capability, as shown by Examples 8-11.

[0074] Based on the disclosure and teachings of the foregoing description, those skilled in the art may make alterations and modifications to the embodiments described above. Therefore, the present invention is not limited to the specific embodiments disclosed and described above, and modifications and alterations of the present invention are also intended to fall within the protection scope of the claims of the present invention. In addition, although certain specific terms are used in this description, these terms are chosen merely for convenience of description and do not constitute any limitation on the present invention.



DECLARATION OF TRANSLATOR

I, Johnson Wong, hereby declare as follows:

1. I personally performed the attached translation from Chinese into English of Chinese Patent, application publication No. CN109509909A, published/issued 2019.03.22, and entitled "二次电池" ("Secondary Battery").
2. The attached translation is, to the best of my knowledge and belief, a true, full, and accurate English translation of the above-identified Chinese-language document.
3. I am competent to perform this translation because I have a B. Eng bachelor's degree and 20 years' experience translating technical documents from Chinese to English.
4. I declare under penalty of perjury under the laws of the United States that the foregoing is true and correct, and I further declare that I am aware that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of any patent or proceeding resulting therefrom.

Dated: June 16, 2026

A handwritten signature in black ink, appearing to read "Johnson Wong", written over a horizontal line.

Johnson Wong

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