

METHOD FOR MANUFACTURING A LITHIUM-ION BATTERY

Technical field of the invention

The present invention relates to the field of batteries, and more particularly to lithium-ion
5 batteries. The invention concerns a new method of manufacturing batteries, and in particular lithium-ion batteries which have a new architecture which gives them an improved service life.

State of the art

10 All-solid-state rechargeable lithium-ion batteries are known. WO 2016/001584 (I-TEN) describes a lithium-ion battery manufactured from anode foils comprising a conductive substrate successively covered with an anode layer and an electrolyte layer, and cathode
15 foils comprising a conductive substrate successively covered with a cathode layer and an electrolyte layer; these foils are cut, before or after deposition, according to U-shaped patterns. These foils are then alternately stacked in order to constitute a stack of several unit cells. The patterns of cutting the anode and cathode foils are placed in a "head-to-tail"
20 configuration so that the stack of the cathodes and anodes is laterally offset. Then an encapsulation system with a thickness of about ten microns is deposited on the stack and in the available cavities present within the stack. This encapsulation system ensures the rigidity of the structure at the cutting planes and protects the battery cell from the atmosphere. Once the stack has been made and encapsulated, it is cut along cutting planes
25 to obtain unit batteries, with the exposure, on each of the cutting planes, of the cathode connection zones and the anode connection zones of the batteries. It is found that during these cuts, the encapsulation system can be torn off, resulting in a discontinuity in the sealing of the battery. It is also known to add terminations (i.e. electrical contacts) where these cathode and anode connection zones are apparent.

It appeared that this known solution may however have some drawbacks. Indeed, depending on the positioning of the electrodes, in particular the proximity of the edges of the electrodes for multilayer batteries and the cleanliness of the cuts, a leakage current may
30 appear on the ends, typically in the form of a creeping short-circuit. This creeping short-circuit decreases the battery performance despite the use of an encapsulation system around the battery and around the cathode and anode connection zones. Moreover, there is sometimes an unsatisfactory deposition of the encapsulation system on the battery, in particular on the edges of the battery at spaces created by the lateral offsets of the
35 electrodes on the edges of the battery.

The present invention aims at overcoming at least in part some drawbacks of the prior art which are mentioned above, in particular at obtaining rechargeable lithium-ion batteries with high energy density and high power density.

It aims in particular at increasing the production efficiency of rechargeable lithium-ion batteries with high energy density and high power density, and at making more efficient encapsulations at lower cost.

It aims in particular at proposing a method which reduces the risk of a creeping or accidental short-circuit and which allows manufacturing a battery having a low self-discharge.

It aims in particular at proposing a method which allows simply, reliably and quickly manufacturing a battery having a very long life service.

It also aims at proposing a method for manufacturing simple, fast and cost-effective batteries.

Objects of the invention

A first object of the invention is a battery for manufacturing at least one battery (1000), each battery comprising at least one anode entity (110) and at least one cathode entity (140), disposed one above the other in an alternating manner in a frontal direction (ZZ) of the battery (1000),

in which battery, said anode entity (110) comprises:
an anode current collector substrate (10), at least one anode layer (20), and possibly a layer of an electrolyte material (30) or a separator (31) impregnated with an electrolyte,
and in which battery said cathode entity (140) comprises
a cathode current collector substrate (40), at least one cathode layer (50), and possibly a layer of an electrolyte material (30) or a separator (31) impregnated with an electrolyte,
said battery (1000) having six faces, namely

- two faces called front faces (F1, F2) which are mutually opposite, in particular mutually parallel, generally parallel to each anode entity (110) and, to each cathode entity (140),
- two faces called lateral faces (F3, F5) which are mutually opposite, in particular mutually parallel; and
- two faces called longitudinal faces (F4, F6), which are mutually opposite, in particular mutually parallel,

given that the first longitudinal face (F6) of the battery comprises at least one anode connection zone (1002) and that a second longitudinal face (F4) of the battery comprises

at least one cathode connection zone (1006), said anode (1002) and cathode (1006) connection zones being laterally opposite,

- each anode entity (110) and each cathode entity (140) comprising a respective primary body (111, 141), separated from a respective secondary body (112, 142) by a free space (113, 143) of any material of electrode, electrolyte and current collector substrate;
- when the battery comprises several free spaces (113), in said frontal direction (ZZ) of the battery;
- the free spaces formed between each primary body (111) and each secondary body (112) of each anode entity (110) are superimposed;
- the free spaces formed between each primary body (141) and each secondary body (142) of each cathode entity (140) are superimposed; and
- the free spaces of each anode entity (110) and each cathode entity (140) are not coincident;

15 said manufacturing method comprising:

- a) making a stack (I) comprising, in top view, x rows with x strictly greater than 1 as well as y line(s) with y greater than or equal to 1, so as to form a number (x*y) of batteries this stack being formed by an alternating succession of strata (SA, SC) respectively cathode (SC) and anode (SA) strata, each cathode stratum (SC) being intended to form a number (x*y) of cathode entities (140) while each anode stratum (SA) is intended to form a number (x*y) of anode entities (110),

each stratum (SA, SC) comprising a plurality of primary preforms (111', 141'), respectively anode (111') and cathode (141') primary preforms, each of which is intended to form a respective primary body (111, 141), a plurality of secondary preforms (112', 142'), respectively anode (112') and cathode (142') secondary preforms, each of which is intended to form a respective secondary body (112, 142), the primary preform (111', 141') and the secondary preform (112', 142') being mutually separated by a zone called empty zone (80", 70"), which is intended to form at least one of said free spaces (113, 143), and when the battery comprises several free spaces (113), in the frontal direction (ZZ) of the battery;

- the empty zones (80") of the different anode strata (SA) are superimposed;
- the empty zones (70") of the different cathode strata (SC) are superimposed; and
- the empty zones (80", 70") of each anode stratum (SA) and each cathode stratum (SC) are not coincident,

b) carrying out a heat treatment and/or a mechanical compression of the stack (I) obtained in step a) so as to form a consolidated stack;

c) making a pair of main cuts (DY_n , DY'_n) between two adjacent empty zones ($80''$, $70''$), in top view, so as to expose the anode connection zone (1002) and the cathode connection zone (1006), and to separate a given battery, formed from a given row (R_n), from at least one other adjacent battery, formed from at least one adjacent row (R_{n+1}).

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According to a first embodiment, each stratum (SA, SC) is formed by a foil in one piece, the empty zones corresponding in particular to material falls in the foil (70 , 80 , $70'$, $80'$).

According to another embodiment, each stratum (SA, SC) is formed by a plurality of independent strips (A_1 , A_2 , A_n , C_1 , C_2 , C_n), the empty zones ($113'$, $143'$) being defined between the edges (LA, LC) facing the adjacent strips.

According to a first variant of the invention, empty zones called small empty zones (80 , 70) referred to as slots are made, each empty zone, called small empty zone, is intended to form a single free space.

According to a second variant of the invention, empty zones called large empty zones ($80'$, $70'$) referred to as notches are made, each large empty zone being intended to form a plurality of free spaces in the same row, in particular all free spaces of said same row (R_n).

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According to an advantageous feature of the invention, the empty zones (70 , $70'$, 80 , $80'$) have a rectangular shape, in particular an I-shape.

According to one feature of the invention, one makes after step b), during a step d), a pair of accessory cuts (DX_n , DX'_n) allowing separating a given line (L_n) from at least one adjacent line (L_{n-1} , L_{n+1}) belonging to said consolidated stack.

According to another feature of the invention, one carries out, during a step e), the impregnation of the consolidated stack obtained in step b) or the impregnation of the line (L_n) of batteries (1000) obtained in step d) when step d) is carried out, by a lithium ion carrier phase such as liquid electrolytes or an ionic liquid containing lithium salts, such that said separator layer (31) is impregnated with an electrolyte;

According to one feature of the invention, one carries out, before step c) and after step e) if the latter is carried out or else, if step e) is not carried out, after step d) if step d) is carried out or else, if steps e) and d) are not carried out, after step b),

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a step f) of encapsulation of the consolidated stack or the line (L_n) of batteries (1000), preferably, in which one covers, by an encapsulation system (95), the outer periphery of the stack (I) or the line (L_n) of batteries (1000), preferably the front faces of the stack (F1, F2) or the line (L_n) of batteries (FF1, FF2), the lateral faces (F3, F5, FF3, FF5) and the
 5 longitudinal faces (F4, F6, FF4, FF6) of the stack (I) or the line (L_n) of batteries (1000), said encapsulation system (95) preferably comprising

- optionally, at least one first cover layer, preferably selected from parylene, parylene type F, polyimide, epoxy resins, silicone, polyamide, sol-gel silica, organic silica and/or a mixture thereof, deposited on the outer periphery of the stack (I) or the line
 10 (L_n) of batteries (1000),
- optionally a second cover layer composed of an electrically insulating material deposited by deposition of atomic layers, on the outer periphery of the stack (I) or on the outer periphery of the line (L_n) of batteries (1000) or on the first cover layer, and
- 15 - at least one third waterproof cover layer, preferably having a water vapor permeance (WVTR) of less than 10^{-5} g/m².d, this third cover layer being composed of a ceramic material and/or a low melting point glass, preferably a glass whose melting point is less than 600°C, deposited on the outer periphery of the stack (I) or on the outer periphery of the line (L_n) of batteries (1000), or the first cover layer,
- 20 given that a sequence of at least one second cover layer and at least one third cover layer can be repeated z times with $z \geq 1$ and deposited on the outer periphery of at least the third cover layer, and that the last layer of the encapsulation system is a waterproof cover layer, preferably having a water vapor permeance (WVTR) of less than 10^{-5} g/m².d and being composed of a ceramic material and/or a low melting point glass.

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According to another feature of the invention, after step c), a step g) is carried out in which one covers at least the anode connection zone (1002), preferably at least the first longitudinal face (F6) comprising at least the anode connection zone (1002), by an anode contact member (97'), capable of ensuring the electrical contact between the stack (I) and
 30 an outer conductive element,

and in that one covers at least the cathode connection zone (1006), preferably at least the second longitudinal face (F4) comprising at least the cathode connection zone (1006), by a cathode contact member (97''), capable of ensuring the electrical contact between the stack (I) and an outer conductive element,

35 step (i) comprising:

- the deposition on at least the anode connection zone (1002) and on at least the cathode connection zone (1006), preferably, on at least the first longitudinal face (F6) comprising at least the anode connection zone (1002), and on at least the second longitudinal face (F4) comprising at least the cathode connection zone (1006), of a first electrical connection layer of material loaded with electrically conductive particles, said first layer being preferably formed of polymeric resin and/or a material obtained by a sol-gel method loaded with electrically conductive particles;
- optionally, when said first layer is formed of polymeric resin and/or a material obtained by a sol-gel method loaded with electrically conductive particles, a drying step followed by a step of polymerisation of said polymeric resin and/or said material obtained by a sol-gel method; and
- the deposition, on the first layer, of a second electrical connection layer comprising a metal foil disposed on the first electrical connection layer.
- optionally, the deposition on the second electrical connection layer, of a third electrical connection layer comprising a conductive ink.

According to yet another feature of the invention, the cuts made in step d) when this step is carried out, and/or in step c), are performed by laser ablation, preferably in that all cuts made in step d) when this step is carried out, and/or in step c) are performed by laser.

The invention also relates to a battery (1000) comprising at least one anode entity (110) and at least one cathode entity (140), disposed one above the other in an alternating manner in a frontal direction (ZZ) to the main plane of the battery (1000), forming a stack (I), in which said anode entity (110) comprises: an anode current collector substrate (10), at least one anode layer (20), and possibly a layer of an electrolyte material (30) or a separator (31) impregnated with an electrolyte, and in which said cathode entity (140) comprises: a cathode current collector substrate (40), at least one cathode layer (50), and possibly a layer of an electrolyte material (30) or a separator (31) impregnated with an electrolyte;

said battery (1000) having six faces, namely

- two faces called front faces (F1, F2) which are mutually opposite, in particular mutually parallel, generally parallel to each anode entity (110), to each cathode entity (140), to the anode current collector substrate(s) (10), to the anode layer(s) (20), to the layer(s) of an electrolyte material (30) or to the layer(s) of separator impregnated with an electrolyte (31), to the cathode layer(s) (50), and to the cathode current collector substrate(s) (40),

- two faces called lateral faces (F3, F5) which are mutually opposite, in particular mutually parallel,
- and two faces called longitudinal faces (F4, F6), which are mutually opposite, in particular mutually parallel,

5 given that the first longitudinal face (F6) of the battery comprises at least one anode connection zone (1002) and that a second longitudinal face (F4) of the battery comprises at least one cathode connection zone (1006), said anode (1002) and cathode (1006) connection zones being laterally opposite, such that:

- 10 - each anode entity (110) and each cathode entity (140) comprises a respective primary body (111, 141), separated from a respective secondary body (112, 142) by a free space (113, 143) of any material of electrode, electrolyte and current collector substrate,
- when the battery comprises several free spaces (113), in a frontal direction (ZZ) to
15 the main plane of the battery,
 - the free spaces formed between each primary body (111) and each secondary body (112) of each anode entity (110) are superimposed,
 - the free spaces formed between each primary body (141) and each secondary body (142) of each anode entity (110) are superimposed, and
 - 20 ➤ the free spaces of each anode entity (110) and each cathode entity (140) are not coincident,

characterised in that the battery comprises an encapsulation system covering at least in part the outer periphery of the stack (I), said encapsulation system (95) covering the front faces of the stack (F1, F2), the lateral faces (F3, F5) and at least in part the longitudinal
25 faces (F4, F6) such that

only the anode (1002) and cathode (1006) connection zones, preferably, the first longitudinal face (F6) comprising at least the anode connection zone (1002), and the second longitudinal face (F4) comprising at least the cathode connection zone (1006),
30 are not covered with said encapsulation system (95), said encapsulation system (95) comprising:

- optionally, a first cover layer, preferably selected from parylene, parylene type F, polyimide, epoxy resins, silicone, polyamide, sol-gel silica, organic silica and/or a mixture thereof, deposited on at least part of the outer periphery of the stack (I),

- optionally a second cover layer composed of an electrically insulating material deposited by deposition of atomic layers, on at least part of the outer periphery of the stack (I), or on the first cover layer,
- at least one third waterproof cover layer, preferably having a water vapor permeance (WVTR) of less than 10^{-5} g/m².d, this third cover layer being composed of a ceramic material and/or a low melting point glass, preferably a glass whose melting point is less than 600°C, deposited on at least part of the outer periphery of the stack (I), or on the first cover layer,

given that when said second cover layer is present,

- 10 a succession of said second cover layer and said third cover layer can be repeated z times with $z \geq 1$ and deposited on the outer periphery of at least the third cover layer, the last layer of the encapsulation system being a waterproof cover layer, preferably having a water vapor permeance (WVTR) of less than 10^{-5} g/m².d and being composed of a ceramic material and/or a low melting point glass.

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- According to an advantageous feature of the battery in accordance with the invention, the anode connection zone (1002), preferably the first longitudinal face (F6) comprising at least the anode connection zone (1002), is covered by an anode contact member (97'), and at least the cathode connection zone (1006), preferably the second longitudinal face (F4) comprising at least the cathode connection zone (1006), is covered by a cathode contact member (97''),
- 20 given that said anode (97') and cathode (97'') contact members are capable of ensuring the electrical contact between the stack (I) and an outer conductive element.

- 25 According to another feature of the battery in accordance with the invention, each of the anode (97') and cathode (97'') contact members comprises:

- a first electrical connection layer, disposed on at least the anode connection zone (1002) and at least the cathode connection zone (1006), preferably on the first longitudinal face (F6) comprising at least the cathode connection zone (1002) and on the second longitudinal face (F4) comprising at least the cathode connection zone (1006),
- 30 this first layer comprising a material loaded with electrically conductive particles, preferably a polymeric resin and/or a material obtained by a sol-gel method, loaded with electrically conductive particles and even more preferably a polymeric resin loaded with graphite, and
- 35

- a second electrical connection layer comprising a metal foil disposed on the first layer of material loaded with electrically conductive particles

According to a first embodiment, the battery in accordance with the invention has a capacity
5 less than or equal to 1 mA h.

According to an alternative embodiment, the battery in accordance with the invention has a capacity greater than 1 mA h.

10 **Figures**

The appended figures, given by way of non-limiting examples, represent different aspects and embodiments of the invention.

[Fig. 1] is a perspective view of anode and cathode foils intended to form a stack according to the battery manufacturing method in accordance with the invention, these anode and
15 cathode foils having empty zones, called small empty zones, i.e. slots.

[Fig. 2] is a top view, illustrating one of the foils, in particular an anode foil, of Figure 1.

[Fig. 3] is a top view, illustrating the stack of anode and cathode foils as well as the small empty zones, i.e. slots formed in adjacent foils, according to the invention.

[Fig. 4] is a top view, on a larger scale, illustrating small empty zones, i.e. slots formed
20 in adjacent foils, according to the invention.

[Fig. 5] is a perspective view, also on a large scale, illustrating these small empty zones, i.e. these slots formed in adjacent foils.

[Fig. 6] is a top view, illustrating a cutting step carried out on different slots formed in the stack of the previous figures.

[Fig. 7] is a top view, illustrating a line of batteries according to the invention obtained after cutting the stack according to the cutting lines DX_n and DX'_n .
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[Fig. 8] is a sectional view, along the section line VIII-VIII which corresponds to the cutting line DX'_n , indicated in Figure 6 illustrating the stack, according to the invention, of anode and cathode foils having slots.

[Fig. 9] is a sectional view, along the section line VIII-VIII which corresponds to cutting line DX'_n , indicated in Figure 6 illustrating the stack, according to the invention, of anode and cathode foils having slots as well as the primary anode body, the secondary anode body, the primary cathode body and the secondary cathode body.
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[Fig. 10] is a perspective view with tearing illustrating a line of batteries in accordance with
35 the invention encapsulated in an encapsulation system, which is obtainable in particular according to the method of the preceding figures.

[Fig. 11] is a perspective view with tearing illustrating a battery in accordance with the invention comprising an encapsulation system, which is obtainable in particular according to the method of the preceding figures.

5 [Fig. 12] is a perspective view with tearing illustrating a battery in accordance with the invention comprising an encapsulation system, which is obtainable in particular according to the method of the preceding figures and illustrating the stack as well as the anode primary body, the anode secondary body, the cathode primary body and the cathode secondary body.

10 [Fig.13] is a sectional view, along the section line VIII-VIII or the cutting line DX'_n, illustrating a battery in accordance with the invention comprising an encapsulation system and contact members, which is obtainable in particular according to the method of the preceding figures.

[Fig. 14] is a perspective view illustrating a battery with tearing according to the prior art.

15 [Fig. 15] is a top view, illustrating the stack of anode and cathode foils as well as the zones called large empty zones, i.e. the notches made in adjacent foils, according to a first variant of the invention.

[Fig. 16] is a top view, illustrating a cutting step carried out on different notches formed in the stack of the previous figure according to the first variant of the invention, and showing the batteries obtained according to this same variant.

20 [Fig. 17] is a top view, illustrating the stack of anode and cathode strips as well as the spacings provided between adjacent strips, according to a second variant of the invention.

[Fig. 18] is a sectional view, along the cutting line DX'_n, indicated in Figure 17 illustrating the stack, according to the second variant of the invention.

[Fig. 19] is a top view, similar to Figure 6, illustrating a variant of the slots formed in the stack.

25 [Fig. 20] is a top view, schematically illustrating a battery which is obtainable thanks to a stack provided with slots according to figure 19.

[Fig. 21] is a top view, similar to Figure 19, illustrating a variant of slots, which does not belong to the present invention.

30 The following references are used in these figures and in the following description:

1000	Battery according to the invention
1002	Anode connection zone
1006	Cathode connection zone
35 100, 100', 100''	Unit cell

10	Anode current collector substrate
20	Anode layer
30	Layer of an electrolyte material / Electrolyte layer
31	Layer of separator impregnated or subsequently impregnated with an
5	electrolyte / Separator layer
50	Cathode layer
40	Cathode current collector substrate
80	Slot in the anode foils, anode slot, anode small empty zone
80'	Anode notch / empty zone called anode large empty zone
10	l_{80} Total width / Total lateral dimension of the anode slot 80
	L_{80} Total length / Total longitudinal dimension of the anode slot
	$L_{80'}$ Total length / Total longitudinal dimension of the anode notch
	$L_{80''}$ Total length / Total longitudinal dimension of the anode free space
70	Slot in the cathode foils, cathode slot, cathode small empty zones
15	70' Cathode notch / empty zone called cathode large empty zones
	l_{70} Total width / Total lateral dimension of the cathode slot 70
	L_{70} Total length / Total longitudinal dimension of the cathode slot
	$L_{70'}$ Total length / Total longitudinal dimension of the cathode notch
	$L_{70''}$ Total length / Total longitudinal dimension of the cathode free space
20	110 Anode entity
	111, 141 Primary body of 110, respectively of 140
	112, 142 Secondary body of 110, respectively of 140
	113, 143 Free space between 111 and 112, respectively between 141 and 142
	140 Cathode entity
25	LA Lateral edges of the anode strips
	LC Lateral edges of cathode strips
	SA, SA ₁ , SA ₂ , ...SA _n Anode stratum
	SC, SC ₁ , SC ₂ , ...SC _n Cathode stratum
	111', 141' Primary preform of SA, respectively of SC

	112', 142'	Secondary preform of SA, respectively of SC
	80', 70"	Empty zone between 111' and 112', respectively between 141' and 142'
5	80"	Free space formed between two neighboring anode strips in a longitudinal direction / anode free space
	70"	Free space formed between two neighboring cathode strips in a longitudinal direction / cathode free space
	L ₁₁₂	Length of the secondary body 110
	L ₁₁₃	Length of the free space between 111 and 112
10	L ₁₄₂	Length of secondary body of 140
	L ₁₄₃	Length of free space between 141 and 142
	C ₁ , C ₂ , C ₃ , C ₄ , C _n , C' ₁ , C' ₂ , C' ₃ , C' ₄ , C' _n	Cathode strip
	A ₁ , A ₂ , A ₃ , A ₄ , A _n , A' ₁ , A' ₂ , A' ₃ , A' ₄ , A' _n	Anode strip
	90	Material falls
15	95	Encapsulation system
	97	Contact member
	97'	Anode contact member
	97'a	Anode contact member lug covering the ends of the adjacent faces F1, F2, F3, F5 at the longitudinal face F6
20	97"	Cathode contact member
	97"a	Cathode contact member lug covering the ends of the adjacent faces F1, F2, F3, F5 at the longitudinal face F4
	L ₁₀₀₀	Length of the battery
25	I	Stack of anode foils having empty zones and cathode foils having empty zones / Stack of at least one unit cell
	2e	Anode foil having empty zones such as slots or notches)
	5e	Cathode foil having empty zones such as slots or notches
	4	Perforated central zone of the anode foil having elementary entities
	6	Peripheral frame of the anode foil having elementary entities
30	7	Perforations present at the four ends of the anode and cathode foils

8		Material bridges between two lines
l_8		Width of the bridges
9		Second material bridges between two rows of slots
L_9		Length of the second material bridges
5	XX	Longitudinal or horizontal direction of the stack / battery
	YY	Lateral or transverse direction of the stack / the battery
	ZZ	Frontal direction of the stack / the battery
	L, L_n, L_{n-1}, L_{n+1}	Slot line / Battery line
	R, R_n, R_{n-1}, R_{n+1}	Slots row
10	PA, PA'	Anode plane
	PC, PC'	Cathode plane
	$DX_{n-1}, DX'_{n-1}, DX_n, DX'_n, DX_{n+1}, DX'_{n+1}$	First pair of cuts called accessory cuts
	$DY_{n-1}, DY'_{n-1}, DY_n, DY'_n, DY_{n+1}, DY'_{n+1}$	Second pair of cuts called main cuts
15	AA	Interface between the encapsulation system and the contact members
	2000	Battery according to the prior art
	200, 200', 200''	Unit cell of a battery according to the prior art
	2002	Anode connection zone of a battery according to the prior art
	2006	Cathode connection zone of a battery according to the prior art
20	295	encapsulation system of a battery according to the prior art
	F1, F2	Front faces of the stack (I) / the battery (1000)
	F3, F5	Lateral faces of the stack (I) / the battery (1000)
	F4, F6	Longitudinal faces of the stack (I) / the battery (1000)
	FF1, FF2	Front faces of the battery line (L_n)
25	FF3, FF5	Lateral faces of the battery line (L_n)
	FF4, FF6	Longitudinal faces of the battery line (L_n)

Description of the invention

One associates with this battery, by convention, the following geometric names:

ZZ the direction called frontal direction, namely perpendicular to the plane of the different stacked layers of the battery according to the invention

XX the direction called longitudinal direction, which is included in the plane of the stacked layers and which is parallel to the largest dimension of these layers forming the stack of the battery according to the invention, in top view, namely in the frontal direction

YY the direction called lateral or transverse direction, which is included in the plane of the stacked layers and which is parallel to the smallest dimension of these layers, in top view.

Also by convention, the two orientations associated with each of these three directions are given with reference to the plane of the foil on which Figure 11 or Figure 12 is reproduced.

For the direction XX, one therefore associates the rightward orientation and the leftward orientation, for the direction YY, one associates the forward orientation and the backward orientation, and for the direction ZZ, one associates the upward orientation and the downward orientation, with reference to the plane of the foil on which Figure 11 or Figure 12 is reproduced.

Also by convention, one defines a first longitudinal orientation **XX'** directed from right to left and a second longitudinal orientation **XX''**, opposite to the first longitudinal orientation **XX'**, namely directed from left to right, with reference to the plane of the foil on which Figure 11 or Figure 12 is reproduced. One defines, always with reference to the plane of the foil on which Figure 11 or Figure 12 is reproduced, a first lateral orientation **YY'** directed from front to rear, a second lateral orientation **YY''**, opposite to the first lateral orientation, a first frontal orientation **ZZ'** directed from the top to the bottom, as well as a second frontal orientation **ZZ''**, opposite to the first frontal orientation.

In order to characterise the barrier properties of an encapsulation system, one refers, in the present description, to the WVTR coefficient (Water Vapor Transmission Rate) which characterises the water vapor permeance of an encapsulation system. The lower the WVTR coefficient, the more waterproof the encapsulation system. The water vapor permeance (WVTR) can be determined using a method which is the subject of the US 7.624.621 and which is also described in the publication "Structural properties of ultraviolet cured polysilazane gas barrier layers on polymer substrates" by A. Morlier et al., published in the journal Thin Solid Films 550 (2014) 85-89.

The present invention aims at manufacturing of a battery as shown in Figure 11 and Figure 12.

With reference to Figures 11 & 12, there is illustrated one **1000** of the batteries according to the invention comprising at least one anode entity **110** and at least one cathode entity

140, disposed one above the other in an alternating manner in a frontal direction **ZZ** of the battery **1000**.

Each anode entity **110** of the battery **1000** according to the invention comprises, IN the frontal direction **ZZ** of the battery **1000**, an anode current collector substrate **10**, at least one
 5 anode layer **20**, and possibly a layer of an electrolyte material **30** or a separator **31** impregnated with an electrolyte.

Each cathode entity **140** of the battery **1000** according to the invention comprises, according to the frontal direction **ZZ** of the battery **1000**, a cathode current collector substrate **40**, at least one cathode layer **50**, and possibly a layer of an electrolyte material **30** or a separator
 10 **31** impregnated with an electrolyte.

As illustrated in Figure 11, the battery **1000** according to the invention has six faces. One defines

- two faces called front faces **F1**, **F2** which are mutually opposite, in the example mutually parallel, generally parallel to each anode entity **110** and, to each cathode entity **140**,
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- two faces called lateral faces **F3**, **F5** which are mutually opposite, in the example mutually parallel; and
- two faces called longitudinal faces **F4**, **F6**, which are mutually opposite, in the example mutually parallel.

20 As represented in Figure 11, the first longitudinal face **F6** of the battery **1000** comprises at least one anode connection zone **1002**. The second longitudinal face **F4** of the battery **1000** comprises at least one cathode connection zone **1006**. In this manner, the anode **1002** and cathode **1006** connection zones are laterally opposite. Moreover, each anode entity **110** and each cathode entity **140** comprises, in a longitudinal direction **XX** of the battery **1000**,
 25 a respective primary body **111**, **141**, separated from a respective secondary body **112**, **142** by a free space **113**, **143** of any material of electrode, electrolyte and current collector substrate. Thus, for each cathode entity **140**, the primary body **141**, the free space **143** of any material of electrode, electrolyte and current collector substrate, and the secondary body **142** are disposed next to each other in a first longitudinal direction **XX'** of the battery
 30 **1000**. Similarly, for each anode entity **110**, the primary body **111**, the free space **113** of any material of electrode, electrolyte and current collector substrate, and the secondary body **112** are disposed next to each other in a second longitudinal direction **XX''**, opposite to the first longitudinal direction **XX'**, of the battery **1000**.

35 As represented in Figure 11, the battery **1000** according to the invention comprises, by way of non-limiting example, several free spaces **113**, **143**, in said frontal direction **ZZ** of the

battery. In this manner, in top view, the free spaces formed between each primary body **111** and each secondary body **112** of each anode entity **110** are superimposed, and the free spaces formed between each primary body **141** and each secondary body **142** of each cathode entity **140** are superimposed. Moreover, the free spaces **113**, **143** of each anode unit **110** and each cathode unit **140** are not coincident.

The battery according to the invention is formed from a stack **I** comprising, in the longitudinal direction **XX**, x rows with x strictly greater than 1 as well as y line(s) with y greater than or equal to 1, so as to form a number $(x*y)$ of batteries.

The stack **I** is formed by an alternating succession of strata respectively cathode **SC**, **SC₁**, **SC₂**, ...**SC_n** and anode **SA**, **SA₁**, **SA₂**, ...**SA_n** strata, each cathode stratum **SC**, **SC₁**, **SC₂**, ...**SC_n** being intended to form a number $(x*y)$ of cathode entities **140** while each anode stratum **SA**, **SA₁**, **SA₂**, ...**SA_n** is intended to form a number $(x*y)$ of anode entities **110**.

Each anode stratum **SA**, **SA₁**, **SA₂**, ...**SA_n** of the stack **I** according to the invention comprises, in the frontal direction **ZZ** of the stack **I**, parallel to the frontal direction **ZZ** of the final battery **1000**, an anode current collector substrate **10**, at least one anode layer **20**, and possibly a layer of an electrolyte material **30** or a separator **31** impregnated with an electrolyte.

Each cathode stratum **SC**, **SC₁**, **SC₂**, ...**SC_n** of the stack **I** according to the invention comprises, in the frontal direction **ZZ** of the stack **I**, parallel to the frontal direction **ZZ** of the final battery **1000**, a cathode current collector substrate **40**, at least one cathode layer **50**, and possibly a layer of an electrolyte material **30** or a separator **31** impregnated with an electrolyte.

Each stratum **SA**, **SA₁**, **SA₂**, ...**SA_n**, **SC**, **SC₁**, **SC₂**, ...**SC_n** comprises:

- a plurality of primary preforms **111'**, **141'**, respectively anode **111'** and cathode **141'** primary preforms, each of which is intended to form a respective primary body **111**, **141**,
- a plurality of secondary preforms **112'**, **142'**, respectively anode **112'** and cathode **142'** secondary preforms, each of which is intended to form a respective secondary body **112**, **142**.

The primary preform **111'**, **141'** and the secondary preform **112'**, **142'** being mutually separated by a zone called empty zone **80''**, **70''**, which is intended to form at least one of said free spaces **113**, **143** of the battery **1000**.

According to the first embodiment of the invention, the method in accordance with the invention comprises firstly a step in which a stack **I** of alternating strata **SA**, **SA₁**,

SA₂, ...SA_n, SC, SC₁, SC₂, ...SC_n is made. In this first embodiment, each of these strata is a foil made in one piece. In the following, these different foils are called, as the case, "anode foils" or "cathode foils". As will be seen in more detail, each anode foil is intended to form the anode of several batteries, and each cathode foil is intended to form the cathode of several batteries. In the example illustrated in Figure 1, there were represented two cathode foils, having small empty zones, i.e. slots **5e**, as well as two anode foils having small empty zones, i.e. slots **2e**. In practice, this stack is formed by a higher number of foils, typically comprised between ten and a thousand. The number of cathode foils having slots **5e** is identical to the number of anode foils having slots **2e** which are used constituting the stack

10 I of alternating foils of opposite polarity.

In an advantageous embodiment, each of these foils has perforations **7** at the four corners thereof so that when these perforations **7** are superimposed, all cathodes and all anodes of these foils are arranged according to the invention, as this will be explained in greater detail hereinafter (see Figures 1, 2, 3 and 15). These perforations **7** can be made by any

15 appropriate means, in particular on anode and cathode foils after manufacture, or on substrate foils **10**, **40** before manufacture of the anode and cathode foils.

Each anode foil comprises an anode current collector substrate **10** coated with an active layer of an anode material **20**, hereinafter anode layer **20**. Each cathode foil comprises a cathode current collector substrate **40** coated with an active layer **20** of a cathode material

20 **50**, hereinafter referred to as cathode layer **50**. Each of these active layers can be solid, and more particularly of dense or porous nature. Moreover, in order to avoid any electrical contact between two active layers of opposite polarities, an electrolyte layer **30** or a layer of separator **31** which is subsequently impregnated with an electrolyte is disposed on the active layer of at least one of these current collector substrates previously coated with the

25 active layer, in contact with the opposite active layer. The electrolyte layer **30** or the separator layer **31**, may be disposed on the anode layer **20** and/or on the cathode layer **50**; the electrolyte layer **30** or the separator layer **31** is an integral part of the anode foil and/or the cathode foil comprising it.

Advantageously, the two faces of the anode **10**, respectively cathode **40**, current collector substrate are coated with an anode layer **20**, respectively with a cathode layer **50**, and optionally with an electrolyte layer **30** or a separator layer **31**, disposed on the anode layer **20**, respectively on the cathode layer **50**. In this case, the anode **10**, respectively cathode **40**, current collector substrate serves as a current collector for two adjacent unit cells **100**, **100'**. The use of these substrates in the batteries allows increasing the production efficiency

35 of rechargeable batteries with high energy density and high power density.

The mechanical structure of one of the anode foils is described hereinafter, given that the other anode foils have an identical structure. Moreover, as will be seen in what follows, the cathode foils have a structure similar to that of the anode foils.

As shown in Figure 2, the anode foil **2e** having slots **80** has a quadrilateral shape, substantially of rectangular type. It delimits a central zone called perforated central zone **4**, in which slots **80** are formed, i.e. empty zones called small empty zones, free of any material of electrode, electrolyte and current collector substrate, which will be described hereinafter. With reference to the positioning of these slots, a direction called lateral or transverse direction **YY** of the foil, which corresponds to the lateral direction of these slots **80**, as well as a direction called horizontal direction **XX** of the foil, perpendicular to the direction **YY** have been defined. The central zone **4** is bordered by a peripheral frame **6** which is solid, namely devoid of slots **80**. The function of this frame **6** is in particular to ensure an easy handling of each foil.

The slots **80** are distributed along lines **L₁** to **L_y**, disposed one below the other, as well as along rows **R₁** to **R_x** provided next to each other. By way of non-limiting examples, in the context of the manufacture of surface mounted component type micro-batteries (hereinafter SMC), the used anode and cathode foils can be plates of 100 mm x 100 mm. Typically, the number of lines of these foils is comprised between 10 and 500, while the number of rows is comprised between 10 and 500. Depending on the desired capacity of the battery, these dimensions may vary and the number of lines and rows by anode and cathode foils can be adapted accordingly. The dimensions of the used anode and cathode foils can, in other words, be modulated according to the needs. As shown in Figure 2, two adjacent lines can be separated by material bridges **8**, the width of which is noted **l₈**, which is comprised between 0.05 mm and 5 mm. Two adjacent rows can be separated by second material bridges **9**, the length of which is denoted **L₉**, which is comprised between 0.05 mm and 5 mm. These material bridges **8**, **9** of anode and cathode foil give these foils a sufficient mechanical rigidity so that they can be easily handled.

The slots **70**, **80** are through slots, namely that they open onto the opposite faces, respectively upper and lower faces of the foil, as will be seen in more detail hereinafter. These slots **70**, **80** preferably have a quadrilateral shape, typically of rectangular type. In the illustrated example, these slots each have an I-shape, which makes them very easy to use. These slots **70**, **80** can be made in a manner known per se, directly on the current collector substrate, before any deposition of anode or cathode materials by chemical etching, by electroforming, by laser cutting, by microperforation or by stamping.

These slots **70**, **80** can also be made:

- on current collector substrates coated with an anode or cathode material layer, or

- on current collector substrates coated with an anode or cathode material layer, itself coated with an electrolyte layer or a separator layer, i.e. on anode or cathode foils.

When the slots **70, 80** are made on such coated substrates, the slots **70, 80** can be made in a manner known per se, for example by laser cutting (or laser ablation), by femtosecond laser cutting, by microperforation or by stamping.

As illustrated in Figure 3, each cathode foil is also provided with different lines and rows of cathode slots **70**, provided in the same number as the anode slots **80** of each anode foil. The cathode foil obtained after making slots **70**, is hereinafter called cathode foil having slots **5e**.

In top view and as illustrated in Figure 3, the cathode slots **70** made in all cathode foils **5e** are coincident, i.e. are mutually superimposed. Similarly, the anode slots **80** made in all anode foils **2e** are coincident, i.e. are mutually superimposed.

One will now describe the slots **70, 80** as illustrated in Figures 3, 4 and 5, given that all slots **80** of the anode foil are identical and that all slots **70** of the cathode foil are identical.

Each anode slot **80** has, preferably, a quadrilateral shape, typically of rectangular type.

On notes:

- I_{80} the width of the entire anode slot **80**, which is typically comprised between 0.25mm and 10mm;
- L_{80} the length thereof which is typically comprised between 0.01 mm and 0.5 mm.

As shown in particular in Figures 4 and 5, the structure of each cathode slot **70** is substantially similar to that of each anode slot **80**, namely that each cathode slot **70** preferably has a quadrilateral shape, typically of rectangular type.

The dimensions of the cathode slots **70** are preferably identical to those of the anode slots **80**.

One notes:

- I_{70} the width of the entire cathode slot **70**, which is typically comprised between 0.25mm and 10mm;
- L_{70} the length thereof which is typically comprised between 0.01 mm and 0.5 mm.

As seen above, the structures of the anode **80** and cathode **70** slots are similar. Moreover, in top view, the anode slots **80** are offset relative to the cathode slots **70**, in the longitudinal direction **XX**. In this manner, in top view, the anode **80** and cathode **70** slots are not coincident and are distinct from each other.

The stack **I** comprises an alternating arrangement of at least one anode foil **2e** having slots **80** and of at least one cathode foil **5e** having slots **70**. Thus, at least one unit cell **100** is obtained, comprising successively an anode current collector substrate **10**, an anode layer **20**, a layer of an electrolyte material **30** and/or a separator layer **31** subsequently
 5 impregnated with an electrolyte, a cathode layer **50**, and a cathode current collector substrate **40**.

This stack **I** is made such that in top view:

- the cathode slots **70** made in all cathode foils **5e** are coincident, i.e. are mutually superimposed,
- 10 - the anode slots **80** made in all anode foils **2e** are coincident, i.e. are mutually superimposed, and
- the anode **80** and cathode **70** slots are not coincident and are distinct from each other.

In the case where said battery comprises a plurality of unit cells **100**, **100'**, **100''**, said unit
 15 cells **100**, **100'**, **100''** are disposed one below the other, namely superimposed in a frontal direction **ZZ** to the main plane of the battery as represented in Figure 11, such that, preferably:

- o the anode current collector substrate **10** is the anode current collector substrate **10** of two adjacent unit cells **100**, **100'**, **100''**, and
- 20 o the cathode current collector substrate **40** is the cathode current collector substrate **40** of two adjacent unit cells **100**, **100'**, **100''**.

It is assumed that the stack **I**, described above, is subjected to steps aimed at ensuring the overall mechanical stability thereof. These steps, of a type known per se, include in particular the heat and/or mechanical treatment of the various different foils **2e**, **5e** having
 25 slots **80**, **70**. As will be seen below, this stack thus consolidated allows the formation of individual batteries, whose number is equal to the product between the number of lines Y and the number of rows X.

To this end, with reference to Figure 6, three lines **L_{n-1}** to **L_{n+1}** have been illustrated, as well
 30 as three rows **R_{n-1}** to **R_{n+1}**. In the following, one calls battery line a line, belonging to the stack, which is intended to form several batteries. The number of batteries formed, for a given line, corresponds to the number of rows of the stack. In accordance with the invention, and when the stack **I** comprises several lines also called hereinafter battery lines **L_n**, a first pair of cuts **DX_n** and **DX'_n** is made, allowing separating a line **L_n** of batteries **1000** given
 35 relative to at least one other line **L_{n-1}**, **L_{n+1}** of batteries formed from said consolidated stack, as represented in Figure 7. Each cut, which is performed right through, namely which

extends over the entire height of the stack, is carried out in a manner known per se. By way of non-limiting examples, mention will be made of cutting by sawing, in particular dicing, guillotine cutting or even laser cutting. In addition, the zones **90** of the foils of the stack, which do not form the batteries, have been illustrated with a dotted filling, while the volume of the slots is left blank.

As shown in particular in Figure 6, which is a view on a larger scale of the slots formed in adjacent foils of Figure 3, each cut DX_n , DX'_n is made in the frontal direction **ZZ** of the battery, indifferently in either orientations. The cuts DX_n and DX'_n are, preferably, mutually parallel and are, preferably, made perpendicular to both the alignment of the anode slots **80** and the cathode slots **70**. The cuts DX_n and DX'_n are made over the entire height of the stack through the anode slots **80** and cathode slots **70**, and this so as to limit the material falls **90**.

With reference again to Figure 6, each final battery is delimited, at the rear and at the front, by the first pair of cuts DX_n and DX'_n , preferably mutually parallel, and, on the left and on the right by a second pair of cuts DY_n and DY'_n , preferably mutually parallel.

In this figure 6, the batteries **1000** have been represented in hatched manner, once obtained according to the first pair of cuts DX_n and DX'_n and according to the second pair of cuts DY_n and DY'_n .

Figure 8 is a sectional view, taken along the section line **VIII-VIII** corresponding to the cutting line DX_n as indicated in Figure 6, which extends through line L_n of batteries. In Figure 8, there is represented the alternating arrangement of two anode foils having slots **2e** and two cathode foils having slots **5e**. In the same figure, the slots **70**, **80**, also illustrated in Figure 6, as well as adjacent unit cells, are referenced according to an advantageous embodiment of the invention.

The anode foil **2e** having small empty zones, i.e. slots comprises an anode current collector substrate **10** coated with an anode layer **20**, itself optionally coated with an electrolyte layer **30** or a layer of separator **31** subsequently impregnated with an electrolyte. Each cathode foil **5e** having small empty zones, ie slots comprises a cathode current collector substrate **40** coated with an active layer of a cathode material **50**, itself optionally coated with an electrolyte layer **30** or a layer of separator **31** subsequently impregnated with an electrolyte. In order to avoid any electrical contact between two active layers of opposite polarity, i.e. between the anode layer **20** and the cathode layer **50**, at least one electrolyte layer **30** and/or at least one layer of separator **31** impregnated or subsequently impregnated with an electrolyte is/are disposed. In Figure 8 a unit cell **100** is represented, comprising

successively an anode current collector substrate **10**, an anode layer **20**, at least one layer of an electrolyte material **30** or a layer of separator **31** impregnated or subsequently impregnated with an electrolyte, a cathode layer **50**, and a cathode current collector substrate **40**.

- 5 Advantageously, the anode current collector substrate **10** of a unit cell **100'** can be joined to the anode current collector substrate **10** of the adjacent unit cell **100''**. Similarly, the cathode current collector substrates of two adjacent unit cells **100**, **100'** can be joined to each other.

10 In an advantageous embodiment, the anode **10**, respectively cathode **40**, current collector substrate can serve as a current collector for two adjacent unit cells, as illustrated in particular in Figure 8. As explained previously, the two faces of the anode **10**, respectively cathode **40**, current collector substrate are coated with an anode layer **20**, respectively with a cathode layer **50**, and optionally coated with an electrolyte layer **30** or a separator layer **31**, disposed on the anode layer **20**, respectively on the cathode layer **50**. This allows
15 increasing the production efficiency of the batteries.

As represented in Figure 8, each anode foil having slots **2e** and each cathode foil having slots **5e** are arranged so that in top view:

- the cathode slots **70** made in all cathode foils **5e** are coincident, i.e. are mutually superimposed,
- 20 - the anode slots **80** made in all anode foils **2e** are coincident, i.e. are mutually superimposed, and
- the anode **80** and cathode **70** slots are not the coincident and are distinct from each other.

25 In Figure 9, there is shown the alternating arrangement of two anode foils having slots **2e** and two cathode foils having slots **5e**. In the same figure, one referenced cutting lines **DY_n**, **DY'_n** allowing separating a battery **1000** from the other batteries of a line **L_n** of batteries, the length of a battery **L₁₀₀₀**, the slots **70**, **80**, also illustrated in Figure 6, as well as adjacent unit cells according to an advantageous embodiment of the invention. In Figure 9, just like in
30 Figure 8, one notes that the second pair of cuts **DY_n**, **DY'_n** is made both through anode entities **110** and cathode entities **140**, namely:

- at a distance **L₁₄₂** from the cathode slots **70** so as to have for each cathode entity **140** of the battery **1000** a primary body **141** separated from a secondary body **142** by a free space **143**, **70** of any material of electrolyte, separator, current collector substrate and electrode, in particular of cathode, and
35

- at a distance L_{112} from the anode slots **80** so as to have for each anode entity **110** of the battery **1000** a primary body **111** separated from a secondary body **112** by a free space **113**, **80** of any material of electrolyte, separator, current collector substrate and electrode, in particular of anode.

5

This feature is particularly advantageous, since it allows improving the quality of the cut relative to the prior art and avoiding the presence of a short-circuit at the longitudinal faces **F6**, **F4** of the battery, avoiding the presence of leakage current, and facilitating electrical contact at the anode **1002** and cathode **1006** connection zones.

10 With reference to Figure 9, and for each unit battery **1000**, one notes:

- **70** the cathode slot, corresponding to the free space **143** existing between the primary body **141** and the secondary body **142** of the cathode entity **140**;
- L_{70} , the length of the entire cathode slot **70** which is typically comprised between 0.01 mm and 0.5 mm, this length L_{70} corresponding to the length L_{143} of the free space **143** existing between the primary body **141** and the secondary body **142** of the cathode entity **140**;
- L_{142} , the length of the secondary body **142** of the cathode unit **140**, which is typically comprised between XXXX mm and XXXXX mm;
- **80** the anode slot, corresponding to the free space **113** between the primary body **111** and the secondary body **112** of the anode entity **110**;
- L_{80} , the length of the entire anode slot **80** which is typically comprised between 0.01 mm and 0.5 mm, this length L_{80} corresponding to the length L_{113} of the free space **113** existing between the primary body **111** and the secondary body **112** of the anode entity **110**;
- L_{112} , the length of the secondary body **112** of the anode entity **110**, which is typically comprised between 0.01mm and 0.5mm.

Advantageously, after making the stack of the anode foils having slots **2e** and cathode foils having slots **5e**, the stack **I** is consolidated by heat and/or mechanical treatment (this treatment can be a thermocompression treatment, comprising the simultaneous application of a pressure and a high temperature). The heat treatment of the stack allowing the assembly of the battery is advantageously carried out at a temperature comprised between 50°C and 500°C, preferably at a temperature below 350°C. The mechanical compression of the stack of the anode foils having slots **2e** and cathode foils having slots **5e** to be assembled is carried out at a pressure comprised between 10 MPa and 100 MPa, preferably between 20 MPa and 50 MPa.

35

Making the consolidated stack of foils which constitute the battery has just been described. It is then possible, when the stack **I** comprises several lines also called hereinafter battery lines L_n , to make a first pair of cuts called accessory cuts DX_n and DX'_n allowing separating a given line L_n of batteries **1000** from at least one other line L_{n-1} , L_{n+1} of batteries formed from said consolidated stack. Each cut, which is performed right through, namely which extends over the entire height of the stack, is carried out in a manner known per se, as indicated above.

When a separator is used as a host matrix of an electrolyte, the previously obtained consolidated stack or the line L_n of batteries **1000** can be impregnated when the initial stack **I** comprises several battery lines L_n and a first pair of cuts (DX_n , DX'_n) was made in order to separate the given line (L_n) of batteries (1000) from at least one other line (L_{n-1} , L_{n+1}) of batteries (1000) formed from said consolidated stack. The impregnation of the previously obtained consolidated stack or the line L_n of batteries **1000** can be carried out, with a lithium ion carrier phase such as liquid electrolytes or an ionic liquid containing lithium salts, such that said separator layer (31) is impregnated with an electrolyte.

In general, within the scope of the present invention, it is possible to impregnate the separator, but also the electrodes. The structure can also include a combination of impregnated solid and/or mesoporous electrodes and/or can include a solid electrolyte and/or an impregnated separator.

After making a consolidated stack **I** or a line L_n of batteries **1000**, possibly impregnated with a lithium ion carrier phase, this stack or this line L_n of batteries **1000** is encapsulated by depositing an encapsulation system **95** to ensure the protection of the battery cell from the atmosphere, as represented in Figure 10.

The battery line L_n thus encapsulated has six faces, namely:

- two faces called front faces **FF1**, **FF2** which are mutually opposite, in the example mutually parallel, generally parallel to the anode entities, generally parallel to the cathode entities, generally parallel to the anode current collector substrate(s) **10**, to the anode layer(s) **20**, to the layer(s) of an electrolyte material **30** or to the layer(s) of separator impregnated with an electrolyte **31**, to the cathode layer(s) **50**, and to the cathode current collector substrate(s) **40**,
- two faces called lateral faces **FF3**, **FF5** which are mutually opposite, in particular mutually parallel and parallel to the lateral faces **F3**, **F5** of the battery **1000**;

- and two faces called longitudinal faces **FF4**, **FF6**, which are mutually opposite, in particular mutually parallel and parallel to the longitudinal faces **F4**, **F6** of the battery **1000**.

The encapsulation system must advantageously be chemically stable, withstand high temperature and be impermeable to the atmosphere in order to perform its function as a barrier layer.

The stack can be covered with an encapsulation system comprising:

- optionally a first dense and insulating cover layer, preferably selected from parylene, parylene type F, polyimide, epoxy resins, silicone, polyamide, sol-gel silica, organic silica and/or a mixture thereof, deposited on the outer periphery of the stack **I** of anode **2e** and cathode **5e** foils, and, preferably, also in the free spaces **113**, **143** present between the primary **111**, **141** and secondary **112**, **142** bodies of each anode entity **110** and each cathode entity **140**; and
- optionally a second cover layer composed of an electrically insulating material, deposited by deposition of atomic layers on the outer periphery of the stack **I** of anode **2e** and cathode **5e** foils, and, preferably, also in the free spaces **113**, **143** present between the primary **111**, **141** and secondary **112**, **142** bodies of each anode entity **110** and each cathode entity **140**, or on said first cover layer; and
- particularly advantageously, at least one third waterproof cover layer, preferably having a WVTR coefficient of less than 10^{-5} g/m².d, this third cover layer being composed of a ceramic material and/or a low melting point glass, preferably a glass whose melting point is less than 600°C, deposited on the outer periphery of the stack **I** of anode **2e** and cathode **5e** foils, and, preferably, also in the free spaces **113**, **143** present between the primary **111**, **141** and secondary **112**, **142** bodies of each anode entity **110** and each cathode entity **140** or on said first cover layer,

given that a sequence of at least one second cover layer and at least one third cover layer can be repeated z times with $z \geq 1$ and deposited on the outer periphery of at least the third cover layer, and that the last layer of the encapsulation system is a waterproof cover layer, preferably having a WVTR coefficient of less than 10^{-5} g/m².d which is composed of a ceramic material and/or a low melting point glass.

This sequence can be repeated z times with $z \geq 1$. It has a barrier effect, which is all the more significant the higher the value of z .

A rigid and waterproof encapsulation is thus obtained, which prevents, in particular, the passage of water vapor at the interface between the encapsulation system and the contact members (see interface **AA** represented in Figure 13).

Typically, the first cover layer, which is optional, is selected from the group formed by: silicones (deposited for example by impregnation or by plasma-enhanced chemical vapor deposition from hexamethyldisiloxane (HMDSO)), resins epoxy, polyimide, polyamide, poly-para-xylylene (also called poly (p-xylylene, but better known as parylene), and/or a mixture thereof. When a first cover layer is deposited, it allows protecting the sensitive elements of the battery from its environment. The thickness of said first cover layer is, preferably, comprised between 0.5 μm and 3 μm .

This first cover layer is useful especially when the electrolyte and electrode layers of the battery have porosities: it acts as a planarization layer, which also has a barrier effect. By way of example, this first layer is capable of lining all accessible surfaces of the stack or the line L_n of batteries **1000**, in particular the outer periphery of the stack or the line L_n of batteries **1000**, to close the access of the through-microporosities present on the surface of the stack **I** or of the line L_n of batteries **1000**.

In this first cover layer, different variants of parylene can be used. It can be made of parylene type C, parylene type D, parylene type N (CAS 1633-22-3), parylene type F, or a mixture of parylene type C, D, N and/or F. Parylene is a dielectric, transparent, semi-crystalline material which has a high thermodynamic stability, excellent resistance to solvents as well as very low permeability. Parylene also has barrier properties. Within the scope of the present invention, parylene type F is preferred.

This first cover layer is advantageously obtained from the condensation of gaseous monomers deposited by Chemical Vapor Deposition (CVD) on the surfaces of the stack of the battery, which allows having a conformal, thin and uniform covering of all accessible surfaces of the stack. This first cover layer is advantageously rigid; it cannot be considered as a soft surface.

The second cover layer, which is also optional, is composed of an electrically insulating material, preferably inorganic. It is deposited by Atomic Layer Deposition (ALD), by PECVD, by HDPCVD (High Density Plasma Chemical Vapor Deposition) or by ICPCVD (Inductively Coupled Plasma Chemical Vapor Deposition), so as to obtain a conformal covering of all accessible surfaces of the stack which is previously covered with the first cover layer. The layers deposited by ALD are very fragile mechanically and require a rigid bearing surface to ensure their protective role. The deposition of a fragile layer on a flexible surface would lead to the formation of cracks, causing a loss of integrity of this protective layer. Moreover, the growth of the layer deposited by ALD is influenced by the nature of the substrate. A layer deposited by ALD on a substrate having zones of different chemical natures will have an inhomogeneous growth, which may cause a loss of integrity of this protective layer. For this

reason, it is preferable for this second optional layer, if it is present, to bear on said first optional layer, which ensures a chemically homogeneous growth substrate.

The ALD deposition techniques are particularly well adapted for covering surfaces having a high roughness in a completely sealed and compliant manner. They allow making conformal layers, free of defects, such as holes (layers called “pinhole free” layers, i.e. free of holes) and represent very good barriers. Their WVTR coefficient is extremely low. The thickness of this second layer is advantageously selected depending on the desired gas tightness level, i.e. the desired WVTR coefficient and depends on the used deposition technique, in particular among ALD, PECVD, HDPCVD and ICPCVD.

- 10 Said second cover layer can be made of ceramic material, of vitreous material or of glass-ceramic material, for example in the form of oxide, of Al_2O_3 , Ta_2O_5 , nitride, phosphates, oxynitride, or siloxane type. This second cover layer preferably has a thickness comprised between 10 nm and 5 μm , preferably between 10 nm and 50 nm.

- 15 This second cover layer deposited by ALD, by PECVD, by HDPCVD or by ICPCVD on the first cover layer allows, on the one hand, ensuring the waterproofness the structure, i.e. preventing the migration of water inside the object and, on the other hand, protecting the first cover layer, preferably of parylene type F, from the atmosphere, in particular air and humidity, thermal exposures in order to avoid its degradation. This second cover layer thus improves the service life of the encapsulated battery.

- 20 Said second cover layer can also be deposited directly on the stack of anode and cathode foils, that is to say in a case where said first cover layer has not been deposited.

- The third cover layer must be waterproof and preferably has a WVTR coefficient of less than 10^{-5} g/m².d. This third cover layer being composed of a ceramic material and/or a low melting point glass, preferably a glass whose melting point is less than 600°C, deposited on the outer periphery of the stack of anode and cathode foils or the first cover layer. The ceramic and/or glass material used in this third layer is advantageously selected from:

- a low melting point glass (typically < 600°C), preferably $\text{SiO}_2\text{-B}_2\text{O}_3$; $\text{Bi}_2\text{O}_3\text{-B}_2\text{O}_3$, $\text{ZnO-Bi}_2\text{O}_3\text{-B}_2\text{O}_3$, $\text{TeO}_2\text{-V}_2\text{O}_5$, PbO-SiO_2 ,
 - oxides, nitrides, oxynitrides, Si_xN_y , SiO_2 , SiON , amorphous silicon or SiC .
- 30 These glasses can be deposited by molding or by dip-coating.

The ceramic materials are advantageously deposited by PECVD or preferably by HDPCVD or by ICP CVD at low temperature; these methods allow depositing a layer having good sealing properties.

- As represented in particular in Figure 10, the stack thus encapsulated or the line L_n of battery **1000** thus encapsulated, is then cut by any appropriate means according to a second pair of cuts DY_n and DY'_n so as to obtain unit batteries and to expose the anode

1002 and cathode **1006** connection zones of each unit battery **1000**. Advantageously and as represented in Figure 10, the line L_n of batteries **100** is cut according to the cutting pairs DY_{n-1} and DY'_{n-1} , DY_n and DY'_n , DY_{n+1} and DY'_{n+1} so as to obtain unit batteries **1000**. In this manner, the cutting lines DY'_{n-1} , DY_n are coincident, just as the cutting lines DY'_n and DY_{n+1} .

5 This allows reducing the number of effective cuts, and thus improving the production efficiency of the batteries.

According to the invention, and in a particularly advantageous manner, the second pair of cuts DY_n , DY'_n as represented in Figure 11, is made both through anode entities **110** and

10 cathode entities **140**, namely:

- at a distance L_{142} from the cathode slots **70** so as to have for each cathode entity **140** of the battery **1000** a primary body **141** separated from a secondary body **142** by a free space **143**, **70** of any material of electrolyte, separator, current collector substrate and electrode, in particular of cathode, and

15 - at a distance L_{112} from the anode slots **80** so as to have for each anode entity **110** of the battery **1000** a primary body **111** separated from a secondary body **112** by a free space **113**, **80** of any material of electrolyte, separator, current collector substrate and electrode, in particular of anode.

Figures 11 and 12 represent a battery with tearing in accordance with the invention.

20 Contact members **97**, **97'**, **97''** (electrical contacts) are added to where the cathode **1006**, respectively anode **1002**, connection zones are apparent. These contact zones are preferably disposed on opposite sides of the stack of the battery to collect current (lateral current collectors). The contact members **97**, **97'**, **97''** are disposed on at least the cathode

25 connection zone **1006** and on at least the anode connection zone **1002**, preferably on the face of the encapsulated and cut stack comprising at least the cathode connection zone **1006** and on the face of the coated and cut stack comprising at least the anode connection zone **1002** (see Figure 13).

Thus, one covers at least the anode connection zone **1002**, preferably at least the first

30 longitudinal face **F6** comprising at least the anode connection zone **1002**, and more preferably the first longitudinal face **F6** comprising at least the anode connection zone **1002** as well as the ends **97'a** of the faces **F1**, **F2**, **F3**, **F5** adjacent to this first longitudinal face **F6**, by an anode contact member **97'**, capable of ensuring the electrical contact between the stack **I** and an outer conductive element. Moreover, one covers at least the cathode

35 connection zone **1006**, preferably at least the second longitudinal face **F4** comprising at least the cathode connection zone **1006**, and more preferably the second longitudinal face

F4 comprising at least the cathode connection zone **1006** as well as the ends **97''a** of the faces **F1**, **F2**, **F3**, **F5** adjacent to this second longitudinal face **F4**, by a cathode contact member **97''**, capable of ensuring the electrical contact between the stack **I** and an outer conductive element (see [Figure 13](#)).

5

Preferably, in the vicinity of the cathode **1006** and anode **1002** connection zones as previously indicated, the contact members **97**, **97'**, **97''** consist of, a stack of electrical connection layers comprising successively a first electrical connection layer comprising a material loaded with electrically conductive particles, preferably a polymeric resin and/or a material obtained by a sol-gel method, loaded with electrically conductive particles and even more preferably a polymeric resin loaded with graphite, and a second layer consisting of a metal foil disposed on the first electrical connection layer.

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The first electrical connection layer allows fastening the second subsequent electrical connection layer while providing "flexibility" to the connectivity without breaking the electrical contact when the electrical circuit is subjected to thermal and/or vibratory stresses.

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The second electrical connection layer is advantageously a metal foil. This second electrical connection layer is used to permanently protect the batteries from humidity. In general, for a given thickness of material, metals allow making very waterproof films, more waterproof than those based on ceramics and even more waterproof than those based on polymers which are generally not very hermetic to the passage of water molecules. It allows increasing the calendar service life of the battery by reducing the WVTR coefficient at the contact members.

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Advantageously, a third electrical connection layer comprising a conductive ink can be deposited on the second electrical connection layer; it is used to reduce the WVTR coefficient, which increases the service life of the battery.

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The contact members **97**, **97'**, **97''** allow resuming the alternately positive and negative electrical connections on each of the ends. These contact members **97**, **97'**, **97''** allow making the electrical connections in parallel between the different battery elements. For this, only the cathode connections are available on one end, and the anode connections are available on another end.

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The application WO 2016/001584 describes stacks of several unit cells, consisting of anode and cathode foils stacked alternately and laterally offset (see [Figure 14](#)), encapsulated in an encapsulation system **2095** to ensure the protection of the cell of the battery **2000** from the atmosphere. The cutting of these encapsulated stacks allowing obtaining unit batteries, with exposed anode **2002** and cathode **2006** connections zones, is carried out according to

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a section plane crossing an alternating succession of electrode and encapsulation system. Due to the difference in density existing between the electrode and the encapsulation system of the battery of the prior art, the cut made according to this section plane induces a risk of tearing of the encapsulation system in the vicinity of the section plane, and thus the creation of short-circuits. In the application WO 2016/001584, during encapsulation, the encapsulation layer fills the interstices of the stack of foils carrying U-shaped cuts. This encapsulation layer introduced at these interstices is thick and does not adhere very well to the stack, inducing this risk of tearing of the encapsulation system **2095** during the subsequent cutting.

10 According to the present invention, this risk is eliminated with the use of foils according to the invention carrying slots where, in top view:

- the cathode slots **70** (which will form the free spaces **143, 70** of any material of electrolyte, separator, current collector substrate and electrode, in particular of cathode) made in all cathode foils **5e** are coincident, i.e. are mutually superimposed,
- 15 - the anode slots **80** (which will form the free spaces **113, 80** of any material of electrolyte, separator, current collector substrate and electrode, in particular of anode) made in all anode foils **2e** are coincident, i.e. are mutually superimposed, and
- the anode **80** and cathode **70** slots are not the coincident and are distinct from each other.

20 In this manner, each cathode entity **140** of the battery **1000** comprises a primary body **141** separated from a secondary body **142** by a free space **143, 70** of any material of electrolyte, separator, current collector substrate and electrode, in particular of cathode. Similarly, each anode entity **110** of the battery **1000** comprises a primary body **111** separated from a secondary body **112** by a free space **113, 80** of any material of electrolyte, separator, current collector substrate and electrode, in particular of anode (see Figure 11).

The heat-pressed mechanical structure of the stack is extremely rigid in the vicinity of the cuts along the cutting lines **DY'_n** and **DY_n**, due to the alternating superimposition of cathode and anode foils. The use of such a rigid structure, with the use of foils carrying slots, allows reducing the number of defects during the cuts, increasing the cutting speed, improving the production efficiency of the batteries while minimising the material falls.

30 According to the invention, the cuts **DY'_n** and **DY_n** are performed through anode foils having slots **2e** and cathode foils having slots **5e** of comparable density inducing a clean cut of better quality. In addition, the presence of a free space of any material of electrode, electrolyte and/or current collector substrate prevents any risk of short-circuit.

As represented in Figure 11, each cathode entity **140** includes a primary body **141**, a secondary body **142**, as well as a space **143** free of any material of electrode, electrolyte and/or current collector substrate. The latter, whose length L_{70} , L_{143} corresponds to that of the cathode slot **70** described above, extends in a lateral direction **YY** over the entire width of the battery **1000**. Similarly, each anode entity **110** comprises a main body **111**, a secondary body **112** as well as a space **113** free of any material of electrode, electrolyte and/or current collector substrate. The latter, whose length L_{80} , L_{113} corresponds to that of the anode slot **80** described above, extends in a lateral direction **YY** over the entire width of the battery **1000**.

The anode connection zones **1002** and the cathode connection zones **1006** are preferably laterally opposite as illustrated in Figures 11 and 12.

The singular structure of the battery according to the invention allows avoiding the presence of a short-circuit at the longitudinal faces **F4**, **F6** of the battery, avoiding the presence of leakage current and facilitating the electrical contact points at the anode **1002** and cathode **1006** connection zones.

The batteries according to the invention can be made according to different variants. Figures 15 and 16 illustrate a variant of the first embodiment of the invention. The only difference, between the variant of these Figures 15 and 16 and the main variant above, lies in the fact that the anode and cathode foils no longer have slots **70**, **80** (empty zones called small empty zones, free of any material of electrode, electrolyte and/or current collector substrate) but notches **70'**, **80'**. These notches form zones called large empty zones, free of any material of electrode, electrolyte and/or current collector substrate. In this variant, the anode notches **80'**, respectively the cathode notches **70'**, are distributed next to each other in rows **R1** to **Rn**. These anode notches **80'**, respectively cathode notches **70'**, preferably have the quadrilateral shape, typically of rectangular type. In the illustrated example, these notches also have an I-shape, like the slots of the first embodiment. However, as is apparent from the above, these notches **70'**, **80'** are significantly more elongated than the slots, namely, they have a longitudinal dimension much greater than that of these slots. Consequently, the variation of Figures 15 and 16 differs from the main variation above, in that both each anode notch **80'** and each cathode notch **70'** is common to all lines L_1 to L_y , disposed one below the other.

In this manner, the slot 70, 80 positioned in line L_n is coincident with at least one of the adjacent slots positioned in line L_{n-1} and/or L_{n+1} . In this case and as illustrated in Figure 15, the two adjacent lines are not separated by material bridges.

Two adjacent rows, however, are separated by material bridges 9 which give the anode and cathode foils a sufficient mechanical rigidity so that they can be easily handled.

It is assumed that the stack of anode and cathode foils, described above, is subjected to steps aimed at ensuring its overall mechanical stability. These steps, of a type known per se, include in particular the heat treatment and/or the mechanical compression of the stack of the different foils, as has been previously described. As previously indicated, this stack allows the formation of individual batteries, the number of which is equal to the product between the number of lines Y and the number of rows X.

To this end, with reference to Figure 16, three lines L_{n-1} to L_{n+1} , as well as three rows R_{n-1} to R_{n+1} , have been illustrated. In accordance with the invention, a first pair of cuts DX_n and DX'_n are made per line. Each cut, which is performed right through, namely which extends over the entire height of the stack, is carried out in a manner known per se, as indicated above.

The subsequent steps of impregnating, encapsulating, cutting along the cutting lines DY_n and DY'_n , depositing the contact members on at least the anode and cathode connection zones are, advantageously, carried out as previously. The fact of using notches 70', 80' according to the first variant instead of slots 70, 80 allows reducing the material falls 90 and thus optimising the production of unit battery 1000. The battery 1000 obtained according to the first variant of the invention is in every aspect identical to that obtained according to the invention even though the arrangement of the notches 70', 80' is different.

Figures 17 and 18 illustrate a second embodiment of the invention. The main difference between this second embodiment and the first embodiment described above, lies in the shape of the strata of the stack. As seen above, the first embodiment uses strata each formed by foils in one piece. However, in the second embodiment, each stratum is formed by a succession of strips, disposed next to each other according to respectively anode PA and cathode PC plane, which corresponds to the plane formed by a foil of the first embodiment.

In Figure 18, only the first four strata are represented, namely the first two anode strata SA_1 and SA_2 , as well as the first 2 cathode strata SC_1 and SC_2 . Each anode stratum is formed by a succession of anode strips A_1 to A_x and A'_1 to A'_x , of which only the first 4 A_1 to A_4 and A'_1 to A'_4 are represented in Figures 17 and 18, while each cathode stratum is formed by a

succession of cathode strips C_1 to C_x and C'_1 to C'_x , of which only the first 4 C_1 to C_4 and C'_1 to C'_4 are represented in the figures. For each stratum, both anode and cathode strata, the number of strips corresponds to the number of rows. Moreover, for each stratum, the opposite lateral edges LA and LC of the adjacent strips define free spaces **80"** and **70"** respectively.

These anode **A_1, A_2, A_3, A_4** , respectively cathode **C_1, C_2, C_3, C_4** , strips preferably have a quadrilateral shape, typically of rectangular type.

10 These anode, respectively cathode, strips have the same chemical structure as the anode, respectively cathode, foils used according to the invention or according to the first variant of the invention.

This second embodiment therefore differs, in other words, from the first embodiment essentially in that the different strips, respectively anode and cathode strips, are independent of each other.

In this manner, each anode **A_1, A_2, A_3, A_4** , respectively cathode **C_1, C_2, C_3, C_4** , strip is not connected to a solid peripheral frame so as to form an anode, respectively cathode, foil as previously indicated.

According to the second embodiment of the invention, for a given row R_x , the anode strip **A_1, A_2, A_3, A_4** is common to all lines L_1 to L_y , disposed one below the other, and the cathode strip **C_1, C_2, C_3, C_4** is common to all lines L_1 to L_y , arranged one below the other.

25 According to the second embodiment of the invention and as illustrated in Figure 18, the anode strips **A_1, A_2, A_3, A_4** , aligned along the anode plane **PA** parallel to the main plane of the battery, the cathode strips **C_1, C_2, C_3, C_4** aligned along the cathode plane **PC** parallel to the main plane of the battery, the free spaces **80"** formed between two neighboring anode strips **A_1, A_2** in a longitudinal direction and the free spaces **70"** formed between two neighboring cathode strips **C_1, C_2** in a longitudinal direction are disposed so that:

- each anode strip **A_n** positioned in the row **R_n** is partially used as a secondary body of a battery **1000** positioned in the row **R_{n-1}** , and partially used as the primary body of a battery **1000** positioned in the row **R_n** , and
- each cathode strip **C_{n+1}** is partially used as a secondary body of a battery **1000** positioned in the row **R_{n+1}** , and partially used as the primary body of a battery **1000** positioned in the row **R_n** .

It is assumed that the stack of anode and cathode strips, described above, is subjected to steps aimed at ensuring its overall mechanical stability. These steps, of a type known per se, include in particular the heat treatment and/or the mechanical compression of the stack of the different strips, as has been previously described. As previously indicated, this stack allows the formation of individual batteries, whose number is equal to the product between the number of lines Y and the number of rows X.

To this end, with reference to Figure 17, three lines L_{n-1} to L_{n+1} , as well as three rows R_{n-1} to R_{n+1} have been illustrated. In accordance with the invention, a first pair of cuts DX_n and DX'_n are made per line. Each cut, which is performed right through, namely which extends over the entire height of the stack, is carried out in a manner known per se, as previously indicated.

The subsequent steps of impregnating, encapsulating, cutting along the cutting lines DY_n and DY'_n , as illustrated in Figure 18, depositing the contact members on at least the anode and cathode connection zones are, advantageously, carried out as previously indicated. The fact of using anode A_1, A_2, A_3, A_4 , and cathode C_1, C_2, C_3, C_4 strips according to the second variant allows reducing material falls **90** and thus optimising the production of unit batteries **1000**. The battery **1000** obtained according to the second embodiment of the invention is in every aspect identical to that obtained according to the first embodiment from foils having small or large empty zones, even though the arrangement of the anode A_1, A_2, A_3, A_4 , and cathode C_1, C_2, C_3, C_4 strips is different.

Figure 19 illustrates a variant of the embodiment illustrated in Figure 6. The stack of this Figure 19 differs from that described in Figure 6, in that each empty zone 70, 80 is extended by a respective channel 75, 85. Each channel extends transversely from the empty zone, beyond the opposite cutting line DY_1 or DY_2 . In this manner, this channel can be passed through when making this cut.

Different possibilities can be considered, with regard to the structure of these channels. Typically, the anode channels 85 are mutually superimposed, as are the cathode channels 75. Moreover, each anode channel is typically located in the extension of a cathode channel, given that an offset arrangement can be provided. Moreover, it can be provided to make, for the same empty zone, several anode channels and/or several cathode channels. In the direction Z, it can be provided that each channel extends over the entire height of the empty zone. Alternatively, this channel can extend over only part of this height, either in the upper portion, or in the lower portion, or even in the middle portion.

The presence of these channels, both anode and cathode channels, provides specific advantages. Indeed, these channels allow, in particular, promoting the impregnation of the electrolyte.

5 Figure 20 illustrates the final battery 1000, once made according to the method implemented thanks to the foils partially represented in Figure 19. Each battery includes anode 115 and cathode 145 cavities, extending into a secondary body 112 and 142 from a respective free space 113 and 143. It will be noted that these cavities, which are formed from the above channels, however have a shorter length. Indeed, as has been mentioned,
10 the channels extend beyond the cutting line. However, the cavities 115 and 145 extend only to the opposite longitudinal faces F4 and F6 of the battery, which are delimited by these cuts.

Figure 21 shows an additional variant, which does not fall within the scope of the present
15 invention. This variant is based in particular on the teaching of international patent application WO 2020 136313 on behalf of the applicant, in which the empty zones have an overall H shape. According to the teaching of this document, each empty zone, such as that 570 or 580 of Figure 21, includes two main recesses 571 or 581 as well as 572 or 582, which are mutually connected by a junction conduit 573 or 583.

20 According to the variant of Figure 21, channels 575 and 585 are made, each of which extends a respective conduit 573 and 583, by being parallel to the main recesses. As in the embodiment of Figure 19, each channel extends beyond a respective cutting line DY1 and DY2. The associated technical effect is to be compared to that of the embodiment of Figures
25 19 to 20, namely that the presence of the channel 575 or 585 ensures a better impregnation of the electrolyte.

The method according to the invention is particularly adapted for the manufacture of fully solid batteries, i.e. batteries whose electrodes and electrolyte are solid and do not comprise
30 a liquid phase, even impregnated in the solid phase.

The method according to the invention is particularly adapted for the manufacture of batteries considered to be quasi-solid comprising at least one separator **31** impregnated with an electrolyte. The separator is preferably a porous inorganic layer having:

- a porosity, preferably a mesoporous porosity, greater than 30%, preferably comprised
35 between 35% and 50%, and even more preferably between 40% and 50%,
- pores of average diameter D_{50} less than 50 nm.

The thickness of the separator is advantageously less than 20 μm , and preferably comprised between 5 μm and 10 μm , so as to reduce the final thickness of the battery without reducing its properties. The pores of the separator are impregnated with an electrolyte, preferably with a lithium ion carrier phase such as liquid electrolytes or an ionic liquid containing lithium salts. The liquid which is "nano-confined" or "nano-trapped" in the porosities, and in particular in the mesoporosities, can no longer come out. It is linked by a phenomenon called herein "absorption in the mesoporous structure" (which does not seem to have been described in the literature in the context of lithium-ion batteries) and it can no longer come out even when the cell is put under vacuum. The battery is then considered as quasi-solid.

The battery according to the invention can be designed and dimensioned so as to have:

- a capacity less than or equal to about 1 mA h (commonly called "microbattery"),
- or a capacity greater than about 1 mA h.

Typically, the microbatteries are designed to be compatible with microelectronics manufacturing methods.

The batteries of each of these power ranges can be made:

- either with "all solid" type layers, i.e. devoid of impregnated liquid or pasty phases (said liquid or pasty phases can be a conductive medium of lithium ions, capable of acting as an electrolyte),
- either with mesoporous "all solid" type layers, impregnated with a liquid or pasty phase, typically a lithium ion conductive medium, which spontaneously enters inside the layer and which no longer comes out from this layer, such that this layer can be considered as quasi-solid,
- or with impregnated porous layers (i.e. layers having a network of open pores which can be impregnated with a liquid or pasty phase, and which gives these layers wet properties).

CLAIMS

1. A method for manufacturing at least one battery (1000), each battery comprising at least one anode entity (110) and at least one cathode entity (140), disposed one above the other in an alternating manner in a frontal direction (ZZ) of the battery (1000),
in which battery, said anode entity (110) comprises:
an anode current collector substrate (10), at least one anode layer (20), and possibly a layer of an electrolyte material (30) or a separator (31) impregnated with an electrolyte,
and in which battery said cathode entity (140) comprises
a cathode current collector substrate (40), at least one cathode layer (50), and possibly a layer of an electrolyte material (30) or a separator (31) impregnated with an electrolyte,
said battery (1000) having six faces, namely
 - two faces called front faces (F1, F2) which are mutually opposite, in particular mutually parallel, generally parallel to each anode entity (110) and, to each cathode entity (140),
 - two faces called lateral faces (F3, F5) which are mutually opposite, in particular mutually parallel; and
 - two faces called longitudinal faces (F4, F6), which are mutually opposite, in particular mutually parallel,
given that the first longitudinal face (F6) of the battery comprises at least one anode connection zone (1002) and that a second longitudinal face (F4) of the battery comprises at least one cathode connection zone (1006), said anode (1002) and cathode (1006) connection zones being laterally opposite,
 - each anode entity (110) and each cathode entity (140) comprising a respective primary body (111, 141), separated from a respective secondary body (112, 142) by a free space (113, 143) of any electrode, electrolyte and current collector substrate material;
 - when the battery comprises several free spaces (113), in said frontal direction (ZZ) of the battery;
 - the free spaces formed between each primary body (111) and each secondary body (112) of each anode entity (110) are superimposed;
 - the free spaces formed between each primary body (141) and each secondary body (142) of each cathode entity (140) are superimposed; and
 - the free spaces of each anode entity (110) and each cathode entity (140) are not coincident;
said manufacturing method comprising:

- a) making a stack (I) comprising, in top view, x rows with x strictly greater than 1 as well as y line(s) with y greater than or equal to 1, so as to form a number ($x \cdot y$) of batteries this stack being formed by an alternating succession of strata (SA, SC) respectively cathode (SC) and anode (SA) strata, each cathode stratum (SC) being intended to form a number ($x \cdot y$) of cathode entities (140) while each anode stratum (SA) is intended to form a number ($x \cdot y$) of anode entities (110), each stratum (SA, SC) comprising a plurality of primary preforms (111', 141'), respectively anode (111') and cathode (141') primary preforms, each of which is intended to form a respective primary body (111, 141), a plurality of secondary preforms (112', 142'), respectively anode (112') and cathode (142') secondary preforms, each of which is intended to form a respective secondary body (112, 142), the primary preform (111', 141') and the secondary preform (112', 142') being mutually separated by a zone called empty zone (80", 70"), which is intended to form at least one of said free spaces (113, 143), and when the battery comprises several free spaces (113), in the frontal direction (ZZ) of the battery;
- the empty zones (80") of the different anode strata (SA) are superimposed;
 - the empty zones (70") of the different cathode strata (SC) are superimposed; and
 - the empty zones (80", 70") of each anode stratum (SA) and each cathode stratum (SC) are not coincident,
- b) carrying out a heat treatment and/or a mechanical compression of the stack (I) obtained in step a) so as to form a consolidated stack;
- c) making a pair of main cuts (DY_n, DY'_n) between two adjacent empty zones (80", 70"), in top view, so as to expose the anode connection zone (1002) and the cathode connection zone (1006), and to separate a given battery, formed from a given row (R_n), from at least one other adjacent battery, formed from at least one adjacent row (R_{n+1})
2. The method according to claim 1, characterised in that each stratum (SA, SC) is formed by a foil in one piece, the empty zones corresponding in particular to material falls in the foil (70, 80, 70', 80').
3. The method according to claim 1, characterised in that each stratum (SA, SC) is formed by a plurality of independent strips (A₁, A₂, A_n, C₁, C₂, C_n), the empty zones (113', 143') being defined between the edges (LA, LC) facing the adjacent strips.

4. The method according to one of the preceding claims, characterised in that empty zones called small empty zones (80, 70) referred to as slots are made, each empty zone, called small empty zone, is intended to form a single free space.
- 5 5. The method according to one of claims 1 to 3, characterised in that empty zones called large empty zones (80', 70') referred to as notches are made, each large empty zone being intended to form a plurality of free spaces in the same row, in particular all free spaces of said same row (R_n).
- 10 6. The method according to one of the preceding claims, characterised in that the empty zones (70, 70', 80, 80') have a rectangular shape, in particular an I-shape.
7. The method according to any one of the preceding claims, characterised in that one makes after step b), during a step d), a pair of accessory cuts (DX_n , DX'_n) allowing
15 separating a given line (L_n) from at least one adjacent line (L_{n-1} , L_{n+1}) belonging to said consolidated stack.
8. The method according to any one of the preceding claims, characterised in that one carries out during a step e), the impregnation of the consolidated stack obtained in step b)
20 or the impregnation of the line (L_n) of batteries (1000) obtained in step d) when step d) is carried out, by a lithium ion carrier phase such as liquid electrolytes or an ionic liquid containing lithium salts, such that said separator layer (31) is impregnated with an electrolyte;
- 25 9. The method according to any one of the preceding claims, characterised in that one carries out, before step c) and after step e) if the latter is carried out or else, if step e) is not carried out, after step d) if step d) is carried out or else, if steps e) and d) are not carried out, after step b),
a step f) of encapsulation of the consolidated stack or the line (L_n) of batteries (1000),
30 preferably, in which one covers, by an encapsulation system (95), the outer periphery of the stack (I) or the line (L_n) of batteries (1000), preferably the front faces of the stack (F1, F2) or the line (L_n) of batteries (FF1, FF2), the lateral faces (F3, F5, FF3, FF5) and the longitudinal faces (F4, F6, FF4, FF6) of the stack (I) or the line (L_n) of batteries (1000),
said encapsulation system (95) preferably comprising,

- optionally, at least one first cover layer, preferably selected from parylene, parylene type F, polyimide, epoxy resins, silicone, polyamide, sol-gel silica, organic silica and/or a mixture thereof, deposited on the outer periphery of the stack (I) or the line (L_n) of batteries (1000),
 - 5 - optionally a second cover layer composed of an electrically insulating material deposited by deposition of atomic layers, on the outer periphery of the stack (I) or on the outer periphery of the line (L_n) of batteries (1000) or on the first cover layer, and
 - 10 - at least one third waterproof cover layer, preferably having a water vapor permeance (WVTR) of less than 10^{-5} g/m².d, this third cover layer being composed of a ceramic material and/or a low melting point glass, preferably a glass whose melting point is less than 600°C, deposited on the outer periphery of the stack (I) or on the outer periphery of the line (L_n) of batteries (1000), or the first cover layer,
- given that a sequence of at least one second cover layer and at least one third cover layer
- 15 can be repeated z times with $z \geq 1$ and deposited on the outer periphery of at least the third cover layer, and that the last layer of the encapsulation system is a waterproof cover layer, preferably having a water vapor permeance (WVTR) of less than 10^{-5} g/m².d and being composed of a ceramic material and/or a low melting point glass.
- 20 10. The method according to any one of the preceding claims, characterised in that after step c), a step g) is carried out in which one covers at least the anode connection zone (1002), preferably at least the first longitudinal face (F6) comprising at least the anode connection zone (1002), by an anode contact member (97'), capable of ensuring the electrical contact between the stack (I) and an outer conductive element,
- 25 and in that one covers at least the cathode connection zone (1006), preferably at least the second longitudinal face (F4) comprising at least the cathode connection zone (1006), by a cathode contact member (97''), capable of ensuring the electrical contact between the stack (I) and an outer conductive element,
- step (i) comprising:
- 30 - the deposition on at least the anode connection zone (1002) and on at least the cathode connection zone (1006), preferably, on at least the first longitudinal face (F6) comprising at least the anode connection zone (1002), and on at least the second longitudinal face (F4) comprising at least the cathode connection zone (1006), of a first electrical connection layer of material loaded with electrically
- 35 conductive particles, said first layer being preferably formed of polymeric resin

and/or a material obtained by a sol-gel method loaded with electrically conductive particles;

- optionally, when said first layer is formed of polymeric resin and/or a material obtained by a sol-gel method loaded with electrically conductive particles, a drying step followed by a step of polymerisation of said polymeric resin and/or said material obtained by a sol-gel method; and
- the deposition, on the first layer, of a second electrical connection layer comprising a metal foil disposed on the first electrical connection layer.
- optionally, the deposition on the second electrical connection layer, of a third electrical connection layer comprising a conductive ink.

11. The method according to any one of the preceding claims, characterised in that the cuts made in step d) when this step is carried out, and/or in step c), are performed by laser ablation, preferably in that all cuts made in step d) when this step is carried out, and/or in step c) are performed by laser.

12. The method according to any one of the preceding claims, characterised in that one forms at least one transverse channel (75, 85) from at least one empty zone (70, 80), in particular from each of a majority of empty zones, in particular each of the set of empty zones, said transverse channel extending at least to an adjacent main cut (DY1, DY2), so as to facilitate the impregnation with the electrolyte.

13. A battery (1000) comprising at least one anode entity (110) and at least one cathode entity (140), disposed one above the other in an alternating manner in a frontal direction (ZZ) to the main plane of the battery (1000), forming a stack (I), wherein said anode entity (110) comprises: an anode current collector substrate (10), at least one anode layer (20), and possibly a layer of an electrolyte material (30) or a separator (31) impregnated with an electrolyte, and wherein said cathode entity (140) comprises: a cathode current collector substrate (40), at least one cathode layer (50), and possibly a layer of an electrolyte material (30) or a separator (31) impregnated with an electrolyte; said battery (1000) having six faces, namely

- two faces called front faces (F1, F2) which are mutually opposite, in particular mutually parallel, generally parallel to each anode entity (110), to each cathode entity (140), to the anode current collector substrate(s) (10), to the anode layer(s)

(20), to the layer(s) of an electrolyte material (30) or to the layer(s) of separator impregnated with an electrolyte (31), to the cathode layer(s) (50), and to the cathode current collector substrate(s) (40),

- two faces called lateral faces (F3, F5) which are mutually opposite, in particular mutually parallel,
- and two faces called longitudinal faces (F4, F6), which are mutually opposite, in particular mutually parallel,

given that the first longitudinal face (F6) of the battery comprises at least one anode connection zone (1002) and that a second longitudinal face (F4) of the battery comprises at least one cathode connection zone (1006), said anode (1002) and cathode (1006) connection zones being laterally opposite, such that:

- each anode entity (110) and each cathode entity (140) comprises a respective primary body (111, 141), separated from a respective secondary body (112, 142) by a free space (113, 143) of any electrode, electrolyte and current collector substrate material,
- when the battery comprises several free spaces (113), in a frontal direction (ZZ) to the main plane of the battery,
 - the free spaces formed between each primary body (111) and each secondary body (112) of each anode entity (110) are superimposed,
 - the free spaces formed between each primary body (141) and each secondary body (142) of each anode entity (110) are superimposed, and
 - the free spaces of each anode entity (110) and each cathode entity (140) are not coincident,

characterised in that the battery comprises an encapsulation system covering at least in part the outer periphery of the stack (I), said encapsulation system (95) covering the front faces of the stack (F1, F2), the lateral faces (F3, F5) and at least in part the longitudinal faces (F4, F6) such that

only the anode (1002) and cathode (1006) connection zones, preferably, the first longitudinal face (F6) comprising at least the anode connection zone (1002), and the second longitudinal face (F4) comprising at least the cathode connection zone (1006), are not covered with said encapsulation system (95), said encapsulation system (95) comprising:

- optionally, a first cover layer, preferably selected from parylene, parylene type F, polyimide, epoxy resins, silicone, polyamide, sol-gel silica, organic silica and/or a mixture thereof, deposited on at least part of the outer periphery of the stack (I),
- 5 - optionally a second cover layer composed of an electrically insulating material deposited by deposition of atomic layers, on at least part of the outer periphery of the stack (I), or on the first cover layer,
- 10 - at least one third waterproof cover layer, preferably having a water vapor permeance (WVTR) of less than 10^{-5} g/m².d, this third cover layer being composed of a ceramic material and/or a low melting point glass, preferably a glass whose melting point is less than 600°C, deposited on at least part of the outer periphery of the stack (I), or on the first cover layer,

given that when said second cover layer is present,

a succession of said second cover layer and said third cover layer can be repeated z times with $z \geq 1$ and deposited on the outer periphery of at least the third cover layer,

- 15 the last layer of the encapsulation system being a waterproof cover layer, preferably having a water vapor permeance (WVTR) of less than 10^{-5} g/m².d and being composed of a ceramic material and/or a low melting point glass.

14. The battery according to claim 13, characterised in that at least the anode connection zone (1002), preferably the first longitudinal face (F6) comprising at least the anode connection zone (1002), is covered by an anode contact member (97'),
- 20 and in that at least the cathode connection zone (1006), preferably the second longitudinal face (F4) comprising at least the cathode connection zone (1006), is covered by a cathode contact member (97''),
- 25 given that said anode (97') and cathode (97'') contact members are capable of ensuring the electrical contact between the stack (I) and an outer conductive element.

15. The battery according to the preceding claim, characterised in that each of the anode (97') and cathode (97'') contact members comprises:
- 30 - a first electrical connection layer, disposed on at least the anode connection zone (1002) and at least the cathode connection zone (1006), preferably on the first longitudinal face (F6) comprising at least the cathode connection zone (1002) and on the second longitudinal face (F4) comprising at least the cathode connection zone (1006),

this first layer comprising a material loaded with electrically conductive particles, preferably a polymeric resin and/or a material obtained by a sol-gel method, loaded with electrically conductive particles and even more preferably a polymeric resin loaded with graphite, and

- 5 - a second electrical connection layer comprising a metal foil disposed on the first layer of material loaded with electrically conductive particles.

16. The battery according to any one of claims 13 to 15, characterised in that it has a capacity less than or equal to 1 mA h.

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17. The battery according to any one of claims 13 to 15, characterised in that it has a capacity greater than 1 mA h.

18. The battery according to any one of claims 13 to 16, characterised in that at least one
15 free space (113, 143), in particular a majority of the free spaces, in particular all free spaces, is extended by a cavity (115, 145) intended to facilitate the impregnation with the electrolyte, said cavity extending through the secondary body (112, 142) to an opposite longitudinal face (F4, F6).

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