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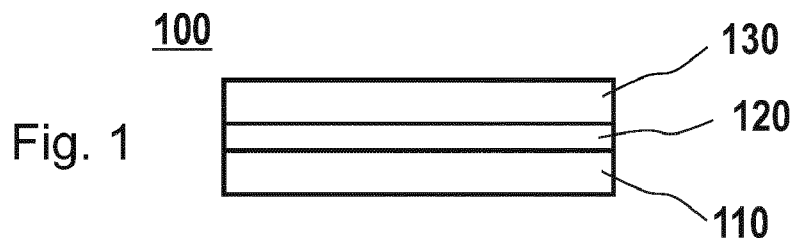
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STACK



(57) Abstract: The present disclosure provides a method for manufacturing a flexible layer stack (100). The method includes: providing (310) a flexible substrate (101); depositing (320) a first layer (110) including a first material over the flexible substrate (101); depositing (330) a second layer (120) including a second material over the first layer (110); and removing (340) the flexible substrate (101).

METHOD AND APPARATUS FOR MANUFACTURING A FLEXIBLE LAYER STACK AND FLEXIBLE LAYER STACK

FIELD

5 [0001] Examples of the present disclosure relate to a method and an apparatus for manufacturing a flexible layer stack, and to a flexible layer stack. Examples of the present disclosure particularly relate to a method and an apparatus for manufacturing a negative electrode of a lithium battery, and to a negative electrode of a lithium battery.

BACKGROUND

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[0002] Several methods are known for depositing a material on a substrate. For instance, substrates may be coated by a physical vapor deposition (PVD) process, a chemical vapor deposition (CVD) process, a plasma enhanced chemical vapor deposition (PECVD) process, etc. Typically, the process is performed in a process apparatus or process chamber
15 in which the substrate to be coated is located. A deposition material is provided in the apparatus. A plurality of materials including oxides, nitrides or carbides thereof may be used for deposition on a substrate. Further, non-vacuum coating methods can be used. For instance, roll-to-roll-coating processes, such as slot die coating, can be used for in a manufacture of lithium (Li) batteries.

20 [0003] Coated materials may be used in several applications and in several technical fields. For instance, coated materials may be used in the field of microelectronics, such as for the manufacture of lithium batteries. Further applications include in general thin film batteries, electrochromic windows, insulating panels, organic light emitting diode (OLED) panels, substrates with TFT, color filters or the like.

25 [0004] In case of lithium batteries, it is desirable to have high energy density or energy storage density, which can be considered as the amount of energy stored in a given system or region of space per unit volume (Wh/l) or mass per weight (Wh/kg). For instance, the

energy density can be increased by combining several cells interconnected by a common anode between two neighboring cells to a lithium battery.

[0005] In view of the above, methods for manufacturing a flexible layer stack, apparatuses for manufacturing a flexible layer stack and flexible layer stack that overcome at least some of the problems in the art are beneficial. The present disclosure aims to provide flexible layers that enable a high energy density and/or are particularly thin.

SUMMARY

[0006] In light of the above, processing chambers and a method for cooling a substrate according to the independent claims are provided. Further aspects, advantages, and features of the present application are apparent from the dependent claims, the description, and the accompanying drawings.

[0007] According to an aspect of the present disclosure, a method for manufacturing a flexible layer stack is provided. The method includes providing a flexible substrate; depositing a first layer including a first material over the flexible substrate; depositing a second layer including a second material over the first layer; and removing the flexible substrate.

[0008] According to a further aspect of the present disclosure, a method for manufacturing a negative electrode of a lithium (Li) battery is provided. The method includes guiding a flexible substrate in a vacuum chamber using a roller arrangement; depositing a first layer including lithium over the flexible substrate; depositing a second layer including copper over the first layer; depositing a third layer including lithium over the second layer; and removing the flexible substrate.

[0009] According to another aspect of the present disclosure, an apparatus for manufacturing a flexible layer stack is provided. The apparatus includes a roller arrangement for guiding a flexible substrate; a first deposition source arrangement configured to deposit a first layer including a first material over the flexible substrate; a second deposition source arrangement configured to deposit a second layer including a

second material over the first layer; and a third deposition source arrangement configured to deposit a third layer including the first material over the second layer.

[0010] According to another aspect of the present disclosure, a negative electrode for a lithium battery is provided. The negative electrode is flexible and includes a first layer including lithium and having a thickness of equal to or more than 5 μm and/or equal to or less than 15 μm ; a second layer including copper and having a thickness of equal to or less than 10 μm ; preferably equal to or less than 8 μm , typically equal to or less than 7 μm , in particular equal to or less than 5 μm ; and a third layer including lithium and having a thickness of equal to or more than 5 μm and/or equal to or less than 15 μm .

[0011] Examples are also directed at apparatuses for carrying out the disclosed methods and include apparatus parts for performing described method blocks. These method blocks may be performed by way of hardware components, a computer programmed by appropriate software, by any combination of the two or in any other manner. Furthermore, examples according to the application are also directed at methods to operate the described apparatus. It includes method blocks for carrying out the functions of the apparatus.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to examples. The accompanying drawings relate to examples of the disclosure and are described in the following:

Fig. 1 shows a schematic view of a flexible layer stack according to examples described herein;

Figs. 2A-C show schematic views of a flexible layer stack according to examples described herein at different processing states;

Figs. 3A-D shows schematic views of a flexible layer stack according to examples described herein at different processing states;

- Fig. 4A-B show schematic views of removal of a flexible substrate from the flexible layer stack according to examples described herein;
- Fig. 5 shows a schematic view of a flexible layer stack according to examples described herein;
- 5 Fig. 6 shows a schematic view of an apparatus for manufacturing a flexible layer stack according to examples described herein;
- Fig. 7 shows a schematic view of an apparatus for manufacturing a flexible layer stack according to examples described herein; and
- Fig. 8 shows a flowchart of a method for manufacturing a flexible layer stack
10 according to examples described herein.

DETAILED DESCRIPTION OF EXAMPLES

[0013] Reference will now be made in detail to the various examples of the disclosure, one or more examples of which are illustrated in the figures. Within the following
15 description of the drawings, the same reference numbers refer to same components. Generally, the differences with respect to individual examples are described. The examples are provided by way of explanation of the disclosure and are not meant as a limitation of the disclosure. Further, features illustrated or described as part of one example can be used on or in conjunction with other examples to yield a further example. It is intended that the
20 description includes such modifications and variations.

[0014] Furthermore, in the following description, a roller or roller device, e.g. as part of a roller arrangement, may be understood as a device, which provides a surface, with which a substrate (or a part of a substrate) may be in contact with during the presence of the substrate in a deposition arrangement (such as a deposition apparatus or deposition
25 chamber). At least a part of the roller device may include a circular-like shape for contacting the substrate. In some examples, the roller device may have a substantially cylindrical shape. The substantially cylindrical shape may be formed about a straight longitudinal axis or may be formed about a bent longitudinal axis. According to some

examples, the roller device as described herein may be adapted for being in contact with a flexible substrate. The roller device as referred to herein may be a guiding roller adapted to guide a substrate while the substrate is coated (or a portion of the substrate is coated) or while the substrate is present in a deposition apparatus; a spreader roller adapted for providing a defined tension for the substrate to be coated; a deflecting roller for deflecting the substrate according to a defined travelling path or the like.

[0015] According to some examples described herein, a flexible substrate, which may also be referred to as film, as described herein may include materials like PET, HC-PET, PE, PI, PU, TaC, one or more metals, paper, combinations thereof, and already coated substrates like Hard Coated PET (e.g. HC-PET, HC-TAC) and the like.

[0016] According to examples described herein, which can be combined with other examples, a method for manufacturing a flexible layer stack, particularly for manufacturing a negative electrode of a lithium (Li) battery, is provided. Therein, a flexible substrate is provided. A first layer including a first material is deposited over the flexible substrate. A second layer including a second material is deposited over the first layer. Then, the flexible substrate is removed. The flexible substrate can be considered as a temporary carrier. According to examples described herein, one or more layers of a predetermined thickness can be deposited on the flexible substrate before it is removed from the layers deposited on the flexible substrate. Specifically, the thickness of the individual layers can be precisely controlled. Further, handling of the flexible layer stack can be improved as the flexible layer can protect the layer deposited thereon from the environment during manufacture.

[0017] Fig. 1 shows a flexible layer stack 100 according to examples described herein. The flexible layer stack 100 shown in Fig. 1 includes a first layer 110, a second layer 120, and a third layer 130. Although the flexible layer stack 100 is shown in Fig. 1 as having three layers, it will be understood by those of ordinary skill in the art that the flexible layer stack 100 can include a greater or smaller number of layers, which can be provided over, under and/or between the first layer 110, the second layer 120, and/or the third layer 130 shown in Fig. 1.

[0018] According to some examples described herein, the first layer 110 can include a first material, and/or the second layer 120 can include a second material. Further, the third layer 130 can include a third material or the third layer 130 can include the first material of the first layer 110. For instance, the first material can be an alkali metal, such as lithium.

5 The second material can be a conductive material, typically a metal, such as copper (Cu) or nickel (Ni). Furthermore, the second layer 120 can include one or more sub-layers. According to some examples described herein, the first material is lithium and the second material is copper. For instance, the second layer 120 can be a current collector layer.

[0019] According to some examples described herein, the first layer 110 can have a
10 thickness equal to or less than about 25 μm , typically equal to or less than 20 μm , specifically equal to or less than 15 μm , and/or typically equal to or greater than 3 μm , specifically equal to or greater than 5 μm . The first layer 110 can be thick enough to provide the intended function and can be thin enough to be flexible. Specifically, the first layer 110 can be as thin as possible so that the first layer 110 can still provide its intended
15 function.

[0020] According to some examples described herein, the second layer 120 can have a thickness of equal to or less than 10 μm , typically equal to or less than 8 μm , beneficially equal to or less than 7 μm , specifically equal to or less than 6 μm , in particular equal to or less than 5 μm . According to some example, the thickness of the second layer 120 can be
20 equal to or less than 4 μm , or equal to or less than 3 μm , or equal to or less than 2 μm .

[0021] The flexible layer stack 100 shown in Fig. 1 can be, e.g., a negative electrode of/for a secondary cell, such as a negative electrode or anode of/for a lithium battery. According to some examples described herein, a flexible negative electrode for a lithium battery includes a first layer 110 including lithium and having a thickness of equal to or
25 more than 5 μm and/or equal to or less than 15 μm , a second layer 120 including copper and having a thickness of equal to or less than 10 μm , typically equal to or less than 8 μm , beneficially equal to or less than 7 μm , specifically equal to or less than 6 μm , in particular equal to or less than 5 μm , and a third layer 130 including lithium and having a thickness of equal to or more than 5 μm and/or equal to or less 15 μm . In case of a lithium battery,
30 the second layer 120 can be a current collector layer.

[0022] For instance, negative electrodes of/for lithium batteries are manufactured by depositing a lithium layer on two sides of a copper foil. In order to reduce the weight of the battery to increase energy storage density per weight (Wh/kg) or per volume (Wh/l), it can be desirable to minimize the amount of material used for the elements of the lithium battery. Typically, a copper foil having a thickness of typically more than 10 μm is used. However, the copper foil and/or the layer stack under manufacture can overheat during deposition of a lithium layer on the copper foil if the layer stack is not well pressed against a coating drum. However, the amount of tension, with which the layer stack under manufacture can be pressed against the coating drum, is limited, especially for thin copper films, since the tension can stretch the copper film.

[0023] Further, lithium can be considered as not being stable in a typical environment, as lithium immediately reacts with humidity. The layer(s) are typically encapsulated and/or protected when the coating system is vented. The system is typically vented with dry nitrogen or argon and the roll exchange can be done in a humidity free dry room. Typically, dry rooms or glove boxes are used for handling or processing of lithium.

[0024] Furthermore, the copper foil can be coated on both sides with lithium. The coated lithium deposited on one side of the copper foil can be protected when it is wound over a roller arrangement for depositing lithium on the other side of the copper foil. For instance, a protection layer or interleaf can be placed on the deposited or coated lithium layer before the lithium layer gets into contact with a roller or drum of the roller arrangement in order to prevent getting damaged by the roller arrangement.

[0025] To obtain lithium batteries having high energy density per kilogram weight of the lithium battery, it may be desirable to minimize the amount of material used for the elements of the lithium battery while maximizing the function of the elements. In the context of a negative electrode, it may be desired to maximize the contacting surface area of the negative electrode in terms of maximizing the function and to minimize its thickness in terms of minimizing its weight. As described above, the typical approach however uses a copper foil having a thickness of typically more than 10 μm . A smaller thickness of the copper foil would still provide the intended function. Currently, however, copper foils cannot be produced thinner than about 8 μm on a commercial scale.

[0026] Figs. 2A to 2C show schematic views of a flexible layer stack 100 according to examples described herein at different processing points of a corresponding manufacturing method.

[0027] Fig. 2A shows a flexible substrate 101. A first layer 110 including a first material is deposited over the flexible substrate 101. Specifically, a sputter process, an evaporation process, for instance a thermal evaporation process, or a CVD process, for instance a plasma enhanced CVD process, can be utilized for depositing layers or thin layers, such as the first layer 110, onto the flexible substrate 101. Further, Roll-to-Roll deposition systems can be used, e.g. in the display industry and the photovoltaic (PV) industry, as well. For instance, roller coating, slot die coating or printing can be used.

[0028] As can be seen from Fig. 2B, a second layer 120 including a second material can be deposited over the first layer 110. The second layer 120 can have a smaller thickness than the first layer 110. In addition or alternatively, the second layer can have a thickness equal to or greater than a thickness of the first layer 110.

[0029] Subsequently, the flexible substrate 101 can be removed from the first layer 110 having the second layer 120 deposited thereon. The obtained flexible layer stack 100 is shown in Fig. 2C. That is, the flexible substrate 101 can be removed from the flexible layer stack 100. Specifically, the flexible layer stack 100 may be considered as not including the flexible substrate 101. The flexible substrate 101 can be considered as a temporary carrier. A “temporary carrier” can be considered as a substrate or carrier that provides support for manufacturing a layer stack, such as the flexible layer stack 100, which can be removed from the layer stack after or during processing of the layer stack. Further, in the context of the present application, a flexible layer stack 100 can also be considered as including the flexible substrate 101.

[0030] Figs. 3A to 3D show schematic views of a flexible layer stack 100 according to further examples described herein at different processing points of a corresponding manufacturing method.

[0031] Fig. 3A shows a flexible substrate 101. A first layer 110 including a first material is deposited over the flexible substrate 101. Specifically, a sputter process, an evaporation

process, for instance a thermal evaporation process, or a CVD process, for instance a plasma enhanced CVD process, can be utilized for depositing layers or thin layers, such as the first layer 110, onto the flexible substrate 101. Further, Roll-to-Roll deposition systems can be used, e.g. in the display industry and the photovoltaic (PV) industry, as well. For instance, roller coating, slot die coating or printing can be used.

[0032] As can be seen from Fig. 3B, a second layer 120 including a second material can be deposited over the first layer 110. The second layer 120 can have a smaller thickness than the first layer 110. In addition or alternatively, the second layer 120 can have a thickness equal to or greater than a thickness of the first layer 110.

[0033] According to Fig. 3C, a third layer 130 can be deposited over the second layer 120. The third layer 130 can include a third material different from the first material and second material. Alternatively, the third layer 130 can include the first material.

[0034] Specifically, the third layer 130 can be formed by the same material or material composition, with a similar or the same structure and a similar or the same thickness as the first layer 110. That is, the second layer 120 can be considered as being interposed between two substantially identical layers, e.g. two layers including the same material and/or structure.

[0035] The flexible substrate 101 can be removed from the first layer 110 having the second layer 120 and the third layer 130 deposited thereon. The obtained flexible layer stack 100 is shown in Fig. 3D.

[0036] For instance, the flexible layer stack 100 shown in Fig. 3D can be the flexible layer stack 100 shown in Fig. 1. That is, by the above described manufacturing method, a flexible layer stack 100 can be obtained.

[0037] For instance, the flexible layer stack 100 shown in Figs. 1 and 3D can be a negative electrode of/for a secondary cell, such as an anode of/for a lithium battery. In this case, the first material can be lithium and the second material can be copper. The first layer 110 and the third layer 130 can be formed to have a thickness of equal to or more than 5 μm and/or equal to or less than 15 μm , and/or the second layer 120 can be formed to have a thickness of equal to or less than 10 μm , typically equal to or less than 8 μm ,

beneficially equal to or less than 7 μm , specifically equal to or less than 6, in particular equal to or less than 5 μm .

[0038] According to some examples described herein, the flexible substrate 101 can be configured to act as a protection layer for the first layer, specifically during manufacturing
5 of the flexible layer stack 100. That is, the flexible substrate 101 can protect the layer deposited thereon, such as the first layer 110, from environmental stress. For instance, lithium is highly reactive and flammable, and lithium corrodes when getting into contact with moisture. The flexible substrate 101 provided on or over a surface of the first layer
10 110 can protect the first layer 110 from getting into contact with the environment and/or from reacting with the environment. Further, the flexible substrate 101 can remain on or over the flexible layer stack 100, e.g. during storage of the flexible layer stack 100, until the flexible layer stack 100 is actually used. Furthermore, for the case that a coating tool including a deposition source without front surface contact is used, the handling of an interleaf can be avoided since the flexible substrate 101 can act as the protection layer
15 and/or interleaf.

[0039] According to some examples described herein, a further protection layer can be provided and/or deposited over the third layer 130, specifically to protect the third layer
20 130 from environmental stress. The further protection layer can include the same material as the flexible substrate 101 or another material that is suitable for protecting the third layer 130.

[0040] According to some examples described herein, the flexible substrate 101 and or the further protection layer can be a barrier film or a metal film which has a low moisture content and/or a low water vapor rate and/or oxygen transmission rate, specifically to
25 protect the first layer 110 and/or the third layer 130, respectively, from reacting with the environment.

[0041] Although a negative electrode of/for a secondary cell and its manufacturing have been described, the present disclosure is not limited thereto. The present disclosure can be applied to any flexible layer stacks, specifically to those which typically apply double side coating of a layer, such as the copper layer described above. That is, the present disclosure
30 provides a method for manufacturing a flexible layer stack by depositing a series of layers

on a flexible substrate and removing the flexible substrate from the layers after deposition of the layers.

[0042] For instance, the disclosed method can be used for manufacturing a flexible layer stack 100 having a metal mesh as first layer 110 and eventually as third layer 130. In this case, an insulating layer may be deposited as second layer 120. Further, a flexible layer stack 100 having an indium tin oxide (ITO) layer or ITO coating as first layer 110 and eventually as third layer 130, and an insulating layer as second layer 120 can be manufactured. The present disclosure can be practiced especially beneficially for flexible layer stacks having a middle layer that is interposed between two similar or substantially identical or identical layers.

[0043] Figs. 4A-B show schematic views of removal(s) of the flexible substrate 101 from the flexible layer stack according to examples described herein.

[0044] According to some examples described herein, a release layer 105 can be provided over, specifically on, the flexible substrate 101. That is, the release layer 105 can be provided between the flexible substrate 101 and the first layer 110. Specifically, the release layer 105 can be deposited over, typically on, the flexible substrate 101, specifically before the first layer 110 is deposited. According to examples described herein, removing the flexible substrate 101 can be facilitated.

[0045] For instance, as shown in Fig. 4A, the release layer 105 can be an etch stop layer 105. According to some examples described herein, removing the flexible substrate 101 includes etching the flexible substrate 101. The flexible substrate 101 can be etched to the first layer 110. In case that an etch stop layer 105 is provided between the flexible substrate 101 and the first layer 110, the etching can be performed until the etch stop layer 105 is reached.

[0046] In the case that an etch stop layer 105 is provided, the first material can be protected from getting into contact with, e.g., the etching solution for etching the flexible substrate. As outlined above, it may be desirable to protect the first layer 110 from environmental stress. By providing an etch stop layer 105, the first layer 110 can be protected from getting into contact with, e.g., the etch solution. Further, the etch stop layer

105 or the remaining portion of the etch stop layer 150 after etching of the flexible substrate 101 can act as a protection layer for protecting the first layer 110 from environmental stress.

[0047] Etching the flexible substrate 101 can include wet etching processes or dry
5 etching processes. The etch stop layer 105 can include a material that has, in consideration of the applied etching process, a lower etch rate than the material of the flexible substrate 101.

[0048] Further, as shown in Fig. 4B, the release layer 105 can be a peeling layer 105. According to some examples described herein, removing the flexible substrate 101
10 includes peeling the flexible substrate 101 off the first layer 110. The flexible substrate 101 can be peeled off the first layer 110. In case that a peeling layer 105 is provided between the flexible substrate 101 and the first layer 110, the flexible substrate 101 and the peeling layer 105 can be peeled off the first layer 110.

[0049] The peeling layer 105 can provide a higher adhesion or adhesive force for the
15 flexible substrate 101 than for the first layer 110. Specifically, the peeling layer 105 can have a lower adhesion or adhesive force for the first layer 110 than the adhesion or adhesive force of the flexible substrate 101 for the first layer 110. The peeling layer can be regarded as a low adhesion layer with respect to first layer 110 or the material of the first layer 110 and a high adhesion layer with respect to the flexible substrate 101 or the
20 material of the flexible substrate 101.

[0050] The peeling layer 105 can be a single layer or include multiple layers that are, e.g., bonded to each other. For instance, the peeling layer 105 can include an adhesive sub-layer facing the flexible substrate 101 and a non-adhesive sub-layer facing the first layer 110. In this context, “non-adhesive” or “non-adhesive sub-layer” can be understood as a
25 layer that has some adhesive properties but its ability to adhere to its adjacent or neighboring layer can be low or lower than that of the “adhesive” sub-layer to its respective adjacent or neighboring layer.

[0051] Furthermore, the release layer 105 can be a laser release layer. According to some examples described herein, removing the flexible substrate 101 includes laser irradiating

the laser release layer. That is, the laser release layer can be an adhesive layer that loses its adhesive properties by irradiation of laser light and/or that gets destroyed by irradiation of laser light. For instance, the laser release layer can be laser irradiated through the flexible substrate 101. In this case, the flexible substrate 101 can include a material that is transparent for the laser light used for irradiating the laser release layer.

[0052] Fig. 5 shows a schematic view of a flexible layer stack 100 according to examples described herein.

[0053] According to some examples described herein, a first adhesion layer 115 can be provided between the first layer 110 and the second layer 120. Specifically, the first adhesion layer 115 can be deposited on or over the first layer 110, typically before the second layer 120 is deposited. According to some examples, the first adhesion layer 115 can have two opposing surfaces, one of the opposing surfaces is in contact with the first layer 110 and the other one of the opposing surfaces is in contact with the second layer 120. An adhesion between the first layer 110 and the second layer 120 can be facilitated. The stability of the flexible layer stack 100 can be improved.

[0054] According to some examples described herein, in which a third layer 130 is provided, a second adhesion layer 125 can be provided between the second layer 120 and the third layer 130. Specifically, the second adhesion layer 125 can be deposited on or over the second layer 120, typically before the third layer 130 is deposited. According to some examples, the second adhesion layer 125 can have two opposing surfaces, one of the opposing surfaces is in contact with the second layer 120 and the other one of the opposing surfaces is in contact with the third layer 130. An adhesion between the second layer 120 and the third layer 130 can be facilitated. The stability of the flexible layer stack 100 can be improved.

[0055] Fig. 6 shows a schematic view of an apparatus 200 for manufacturing a flexible layer stack 100 according to examples described herein.

[0056] The apparatus 200, which can also be referred to as processing apparatus 200, includes a roller arrangement 250 for guiding a flexible substrate 101. One or more processing stations can be provided to process the flexible substrate 101. For instance, a

first deposition source arrangement 210 configured to deposit a first layer 110 including a first material over the flexible substrate 101 can be provided. Further, a second deposition source arrangement 220 configured to deposit a second layer 120 including a second material over the first layer 110 can be provided. Furthermore, a third deposition source arrangement 230 configured to deposit a third layer 130 including a third material or the first material over the second layer 120 can be provided.

[0057] For instance, the first deposition source arrangement 210 can be configured to deposit an alkali metal, such as lithium, over the flexible substrate 101 for forming the first layer 110. The second deposition source arrangement 220 can be configured to deposit a conductive material, typically a metal such as copper, over the first layer 110 for forming the second layer 120. The third deposition source arrangement 230 can be configured to deposit an alkali metal, such as lithium, over the second layer for forming the third layer 130.

[0058] According to examples described herein, each of the first deposition source arrangement 210, the second deposition source arrangement 220 and the third deposition source arrangement 230 can include one or more deposition sources. Specifically, the number of deposition sources per deposition source arrangement, such as the first deposition source arrangement 210, the second deposition source arrangement 220 and the third deposition source arrangement 230, can be adjusted according to the intended thickness of the layer formed by the respective deposition source arrangement. For instance, in case of a negative electrode of/for a lithium battery, it is desired to have thicker lithium layers than the copper layer interposed there-between. The first deposition source arrangement 210 and the third deposition source arrangement 230 can be configured for depositing lithium and include more deposition sources than the second deposition source arrangement 220 configured for depositing copper. As exemplarily shown in Fig. 6, the first deposition source arrangement 210 and the third deposition source arrangement 230 each include two deposition sources whereas the second deposition source arrangement 220 includes one deposition source.

[0059] Further deposition source arrangements can be provided for depositing the peeling layer 105, the first adhesion layer 115 and/or the second adhesive layer 125. Specifically, a deposition source arrangement for depositing the peeling layer 105 can be

provided before the first deposition source arrangement 210 for depositing the first layer 110. A deposition source arrangement for depositing the first adhesive layer 115 can be provided between the first deposition source arrangement 210 for depositing the first layer 110 and the second deposition source arrangement 220 for depositing the second layer 120.

5 A deposition source arrangement for depositing the second adhesive layer 125 can be provided between the second deposition source arrangement 220 for depositing the second layer 120 and the third deposition source arrangement 230 for depositing the third layer 130.

[0060] The apparatus 200 can include a vacuum chamber 205. According to examples
10 described herein, the flexible substrate 101 is guided in the vacuum chamber 205 using the roller arrangement 250. The roller arrangement 250 can include a processing drum 256 or coating drum 256, which can be provided in the vacuum chamber 205. The one or more processing stations can be provided in the vacuum chamber 205 to process the substrate, while the substrate is guided on the processing drum 256. FIG. 6 exemplarily shows three
15 processing stations in the form of five deposition stations forming the first deposition source arrangement 210, the second deposition source arrangement 220 and the third deposition source arrangement 230. Exemplarily, each of the processing stations or the deposition source arrangements can be a rotatable sputtering target or a pair of rotatable sputtering targets or any desired number of rotatable sputtering targets. According to
20 examples described herein, the deposition source arrangements can include linear evaporators, e.g. for lithium.

[0061] Although the vacuum chamber 205 has been described as being a vacuum chamber, in case of non-vacuum disposition techniques, such as roller coating, slot die coating and printing, a chamber 205, e.g. of a dry room or a glove box, can be used.

25 [0062] As further shown in FIG. 6, the coating drum 256 or the processing drum 256 has a rotation axis, which is provided in the apparatus 200. The processing drum 256 has a curved outer surface for guiding the flexible substrate 101 along the curved outer surface. The flexible substrate 101 is guided through a first vacuum processing region and, e.g. at least one second vacuum processing region. Even though it is often referred to herein to
30 deposition source arrangements being the processing stations, also other processing stations, like etch stations, heating stations, etc. can be provided along the curved surface

of the processing drum 256. Accordingly, the apparatuses described herein, which can have compartments for various deposition sources, allow for a modular combination of several sputtering, evaporation, CVD, PECVD and/or PVD processes in a single deposition apparatus, e.g. a R2R coater.

5 [0063] According to some examples described herein, the processing stations can be modularly equipped with different processing tools. The modular concept, wherein all kinds of deposition sources can be used in a processing apparatus or deposition apparatus according to examples described herein, such as the apparatus for manufacturing a flexible layer stack, helps to bring down costs for the deposition of complex layer stacks that have
10 to be deposited applying different deposition technologies or intricate combinations of process parameters.

[0064] Generally, according to some examples described herein, a plasma deposition source can be adapted for depositing a thin film on a flexible substrate, e.g., a web or a foil, a glass substrate or silicon substrate. Typically, the plasma deposition source can be
15 adapted for and can be used for depositing a thin film on the flexible substrate 101, such as the first layer 110 and/or second layer 120 and/or third layer 130, e.g., to form the flexible layer stack 100. The flexible layer stack can be for providing a negative electrode of/for a secondary cell or a TFT, a touch screen device component, or a flexible PV module.

[0065] In accordance with examples described herein, a plasma deposition source can be
20 provided as a PECVD (plasma-enhanced chemical vapor deposition) source having a multi-region electrode device including two, three or even more RF (radio frequency) electrodes arranged opposite to a moving web. According to examples described herein, multi region plasma deposition sources can also be provided for MF (middle frequency) deposition. According to yet further examples describes herein, one or more deposition
25 sources, which are provided in the deposition apparatus as described herein, can be a microwave source and/or can be a sputter source, e.g. a sputter target. For example, for a microwave source, a plasma is excited and maintained by microwave radiation and the source is configured to excite and/or maintain the plasma with microwave radiation.

[0066] As shown in FIG. 6, the flexible substrate 101 can be guided from an unwinding
30 roller 251 to the processing drum 256 and can be wound on to a rewinding roller 257 after

the processing of flexible substrate 101. In order to guide the flexible substrate 101 through the apparatus 200, a plurality of rollers 253 can be provided. The rollers 253 can provide at least one functionality selected from the group consisting of: guiding the flexible substrate 101, tensioning the flexible substrate 101, spreading the flexible substrate 101, charging the flexible substrate 101, de-charging the flexible substrate 101, and heating or cooling the flexible substrate 101.

[0067] According to some examples described herein, the processing drum 256 can be heated or cooled to a desired processing temperature. A controller can be connected to a heating or cooling device within the processing drum 256 by a connection. According to typical examples described herein, the processing drum 256 can be heated for deposition purposes, and can be, e.g., cooled during an etch process. Further, the processing drum 256 can be cooled during deposition of, e.g., material having a low melting point such as lithium.

[0068] According to examples describes herein, a removal arrangement 260 for removing the flexible substrate 101 from the first layer 110 and/or the flexible layer stack 100 can be provided. Specifically, the removal arrangement 260 can be provided in the apparatus 200 after the processing drum 256, typically before the rewinding roller 257. Although the removal arrangement 260 has been described as being provided in the apparatus 200 before the rewinding roller 257, the flexible layer stack 100 can be wound on the rewinding roller 257 including the flexible substrate 101 or having the flexible substrate 101 provided thereon. For instance, the flexible layer stack 100 can be stored with the flexible substrate 101 for protective reasons as described above. In this case, a separate removal arrangement can be provided for removing the flexible substrate 101 before the flexible layer stack is used for its intended operation and/or function. According to some examples described herein, the flexible layer stack 100 can be stored, specifically before the flexible substrate 101 is removed. For instance, in the case of a lithium battery, the flexible substrate 101 can be removed before the battery cell gets assembled.

[0069] FIG. 7 shows a further apparatus 200 for manufacturing a flexible layer stack 100 and/or processing the flexible substrate 101 according to examples described herein.

[0070] The apparatus 200 shown in Fig. 7 is similar to the apparatus shown in Fig. 6. However, the apparatus shown in Fig. 7 includes more than one processing drum. The throughput of the apparatus can be beneficially increased.

[0071] According to examples described herein, a first processing drum 256a can be configured to deposit a first material and a second processing drum 256b can be configured to deposit a second material. That is, the first processing drum 256a can be equipped with a first deposition source arrangement 210 configured to deposit the first material and the second processing drum 256b can be equipped with a second deposition source arrangement 220 configured to deposit the second material. For instance, the first processing drum 256a can be configured to deposit an alkali metal, such as lithium, on the flexible substrate 101 for forming the first layer 110 and to deposit an alkali metal, such as lithium, on the second layer 120, which is still to be formed, for forming the third layer 130. The second processing drum 256b can be configured to deposit a conductive material, typically a metal such as copper, on the first layer 110 for forming the second layer 120.

[0072] That is, the flexible substrate 101 can be unwound from the unwinding roller 251, guided to the first processing drum 256a and the second processing drum by rollers 253, wound on to a rewinding roller 257 after processing the first layer 110 and at least portions of the second layer 120. Then, the flexible substrate 101 can be guided back from the rewinding roller 257 to the unwinding roller 251, passing the second processing drum 256b and the first processing drum 256a, where the eventually remaining portion of the second layer 120 and the third layer 130, respectively, can be deposited. Hence, the flexible substrate 101 can be wound forwards and backwards through the apparatus for manufacturing the flexible layer stack 100.

[0073] As exemplary shown in Fig. 7, a first removal arrangement 260a can be arranged next to the unwinding roller 251 and/or a second removal arrangement 260b can be provided next to the rewinding roller 257. Specifically, a removal arrangement can be beneficially provided next to the one of the unwinding roller 251 and rewinding roller 257 to which the flexible layer stack 100 is wound after processing of the flexible layer stack 100.

[0074] Further, the processing drum, such as the first processing drum 256a and the second processing drum 256b, can be specifically configured for the material to be deposited while the flexible layer stack 100 passes the respective processing drum. For instance, the first processing drum 256a can be cooled during deposition of lithium over the flexible substrate 101 guided on the first processing drum 256a.

[0075] According to examples described herein, the one or more processing drums can be arranged in separate vacuum chambers. In the example shown in Fig. 7, the first processing drum 256a is arranged in a first vacuum chamber 205a, and the second processing drum 256b is arranged in a second vacuum chamber 205b. That is, the process environment in each of the vacuum chambers, such as the first vacuum chamber 205a and the second vacuum chamber 205b, can be adapted for the respective deposition process to be performed in the respective vacuum chamber. In case of lithium deposition, which can be considered as highly contaminating, only the vacuum chamber actually used for lithium deposition is contaminated.

[0076] In the example of Fig., 7, two processing drums 256a, 256b and two vacuum chambers 205a, 205b are shown. However, any number of processing drums and/or vacuum chambers can be provided. For instance, three processing drums can be provided, i.e. a first processing drum, a second processing drum and a third processing drum. The first processing drum can be equipped with the first deposition source arrangement 210, the second processing drum can be equipped with the second deposition source arrangement 220, and the third processing drum can be equipped with the third deposition source arrangement 230. Each of the first deposition source arrangement 210, the second deposition source arrangement 220 and the third deposition source arrangement 230 can include a predetermined number of deposition sources, e.g., depending on the intended thickness of the layer to be formed by the respective deposition source arrangement.

[0077] Further, each of the first processing drum, the second processing drum and the third processing drum can be arranged in a separate vacuum chamber, i.e. in a first vacuum chamber, a second vacuum chamber, and a third vacuum chamber, respectively. Furthermore, one or more processing drums may be arranged in a common vacuum chamber while other processing drums are arranged in different vacuum chamber(s). For instance, the first processing drum and the third processing drum both equipped with

deposition source arrangements configured to deposit the first material, e.g., the first deposition source arrangement 210 and the third deposition source arrangement 230, can be provided in a common vacuum chamber, while the second processing drum equipped with one or more deposition source arrangements configured to deposit the second material, such as the second deposition source arrangement 220, can be arranged in another vacuum chamber. That is, processing drums for depositing the same material can be beneficially arranged in the same vacuum chamber. Furthermore, depending on the deposition process used, chambers of, e.g. a dry room or glove box, can be used instead of the vacuum chambers. For instance, a lithium deposition process can be performed in a chamber of, e.g. a dry room, and/or a copper deposition process can be performed in a vacuum chamber.

[0078] According to some examples, the one or more processing drums 256, which can be considered as being part of the roller arrangement 250, can be heated or cooled to a desired processing temperature. Specifically, the temperature of the flexible substrate 101 can be adjusted by the roller arrangement 250 before the flexible substrate 101 comes into contact with the one or more processing drums 256. In the case of a cooled processing drum, an adjustment control having an under-regulation can adjust the temperature to be slightly above the temperature of the processing drum and an adjustment control having an over-regulation can adjust the temperature to be slightly below the temperature of the processing drum.

[0079] Fig. 8 shows a flowchart of a method 300 for manufacturing a flexible layer stack 100 according to examples described herein.

[0080] The method 300 for manufacturing a flexible layer stack 100 includes, according to block 310, providing a flexible substrate 101. According to block 320, a first layer 110 including a first material is deposited over the flexible substrate 101. According to block 330, a second layer 120 including a second material is deposited over the first layer 110. According to block 340, the flexible substrate 101 is removed. Specifically, the flexible layer stack 100 can be stored and/or transported, typically before the flexible substrate 101 is removed.

[0081] According to examples described herein, a third layer 130 including a third material or the first material can be deposited over the second layer 120. Specifically, the method 300 can include, according to the above or further blocks, deposition of further layers and/or other processing operations, such as tensioning the flexible substrate 101, spreading the flexible substrate 101, charging the flexible substrate 101, de-charging the flexible substrate 101, and heating or cooling the flexible substrate 101.

[0082] According to a specific example described herein, the method 300 can be provided for manufacturing a negative electrode of/for a lithium battery. Therein, a flexible substrate 101 can be guided in a vacuum chamber 205 using a roller arrangement 250. A first layer 110 including lithium can be deposited over the flexible substrate 101. Specifically, the first layer 110 can be a lithium layer. A second layer 120 including copper can be deposited over the first layer 110. Specifically, the second layer 120 can be a copper layer. A third layer 130 including lithium can be deposited over the second layer 120. Specifically, the third layer 130 can be a lithium layer. The flexible substrate 101 can be removed.

[0083] The first layer 110 and the third layer 130 can be formed to a thickness of equal to or less than about 25 μm , preferably equal to or less than 20 μm , typically equal to or less than 15 μm , and/or preferably equal to or greater than 3 μm , typically equal to or greater than 5 μm . The second layer 120 can be formed to a thickness of equal to or less than 10 μm , typically equal to or less than 8 μm , beneficially equal to or less than 7 μm , specifically equal to or less than 6, in particular equal to or less than 5 μm .

[0084] Examples described herein can provide the following benefits. Lithium can be deposited on a temporarily carrier. Temperature control and handling during manufacturing or processing can thus be facilitated. Further, the thickness of the deposited layers, such as a copper layer, can be adjusted. Hence, no limitation of the thickness of the layers occurs, such as on commercial available copper foils. In the context of secondary cells, such as lithium batteries, thin copper layers can be processed. An energy density of the lithium battery, i.e. less weight and volume for same energy storage capability can be increased. Furthermore, efforts, such as coating of the first side, e.g. with lithium, protect the coated layer with a protection film, flip the layer stack to coat the second side, e.g. with lithium, used for double side coating of a certain layer can be saved. Beneficially, the

coating processes or deposition processes can be carried out on a carrier film, such as the flexible substrate, which can itself act as protection or a protection layer, e.g. for the deposited lithium.

[0085] While the foregoing is directed to examples of the disclosure, other and further
5 examples of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

CLAIMS

1. Method for manufacturing a flexible layer stack (100), the method comprising:
providing a flexible substrate (101);
depositing a first layer (110) including a first material over the flexible substrate
5 (101);
depositing a second layer (120) including a second material over the first layer
(110); and
removing the flexible substrate (101).
2. Method of claim 1, further comprising:
10 depositing a third layer (130) over the second layer (120), wherein the third layer
(130) includes the first material.
3. Method of claim 1 or 2, wherein the first material is an alkali metal, such as lithium
4. Method of any one of claims 1 to 3, wherein the first layer (110) is formed to a
thickness equal to or less than about 25 μm , preferably equal to or less than 20 μm ,
15 typically equal to or less than 15 μm , and/or preferably equal to or greater than 3 μm ,
typically equal to or greater than 5 μm .
5. Method of any one of claims 1 to 4, wherein the second material is a conductive
material, preferably a metal, such as copper or nickel, typically wherein the second
material is copper.
- 20 6. Method of any one of claims 1 to 5, further comprising:
guiding the flexible substrate (101) in a vacuum chamber (205) using a roller
arrangement (250).
7. Method of any one of claims 1 to 6, wherein the flexible substrate (101) is
configured to act as a protection layer for the first layer (110), specifically during
25 manufacture of the flexible layer stack (100).

8. Method of any one of claims 1 to 7, wherein removing the flexible substrate (101) includes peeling the flexible substrate (101) off the first layer (110).

9. Method of any one of claims 1 to 8, wherein removing the flexible substrate (101) includes etching the flexible substrate (101).

5 10. Method of any one of claims 1 to 9, further comprising:

providing a release layer (105) over the flexible substrate (101), specifically before depositing the first layer (110), wherein typically the release layer (105) is a peeling layer or an etch stop layer.

11. Method (300) for manufacturing a negative electrode (100) of a lithium battery, the
10 method comprising:

guiding a flexible substrate (101) in a vacuum chamber (205) using a roller arrangement (250);

depositing a first layer (110) including lithium over the flexible substrate (101);

depositing a second layer (120) including copper over the first layer (110);

15 depositing a third layer (130) including lithium over the second layer (120); and
removing the flexible substrate (101).

12. Apparatus for manufacturing a flexible layer stack (100), the apparatus (200) comprising:

a roller arrangement (250) for guiding a flexible substrate (101);

20 a first deposition source arrangement (210) configured to deposit a first layer (110) including a first material over the flexible substrate (101);

a second deposition source arrangement (220) configured to deposit a second layer (120) including a second material over the first layer (110); and

a third deposition source arrangement (230) configured to deposit a third layer
25 (130) including the first material over the second layer (120).

13. Apparatus of claim 12, further comprising:

a removal arrangement (260) for removing the flexible substrate (101) from the first layer (110).

14. Negative electrode for a lithium battery, the negative electrode being flexible and comprising:

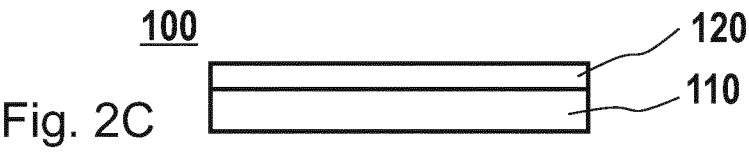
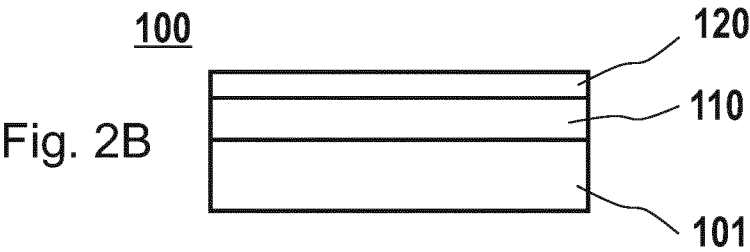
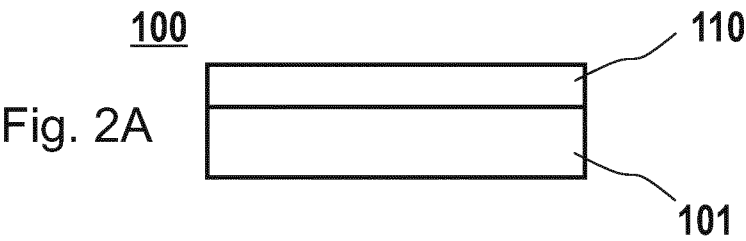
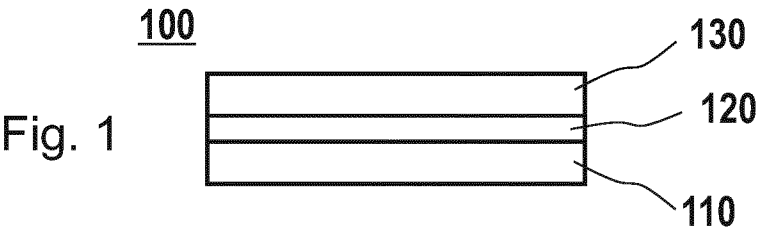
5 a first layer (110) including lithium and having a thickness of equal to or more than 5 μm and/or equal to or less than 15 μm ;

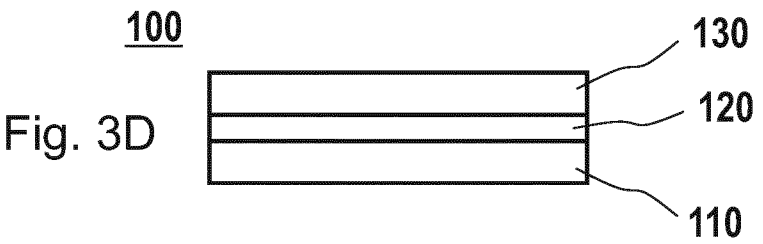
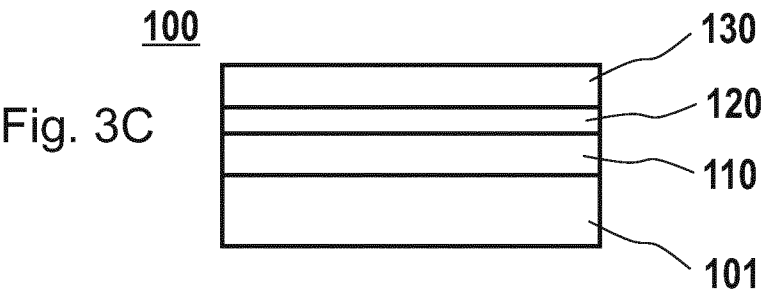
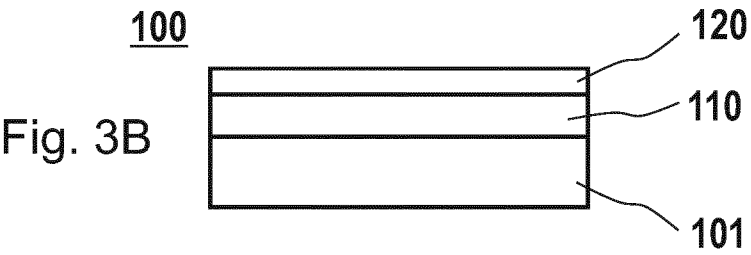
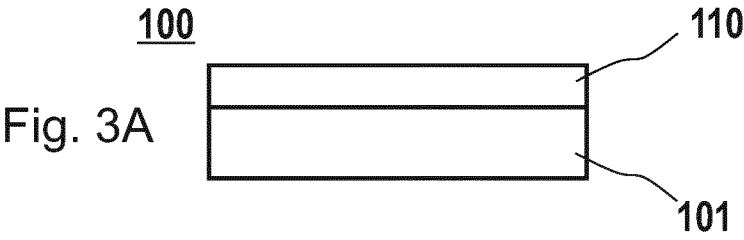
a second layer (120) including copper and having a thickness of equal to or less than 10 μm ; preferably equal to or less than 8 μm , typically equal to or less than 7 μm , in particular equal to or less than 5 μm ; and

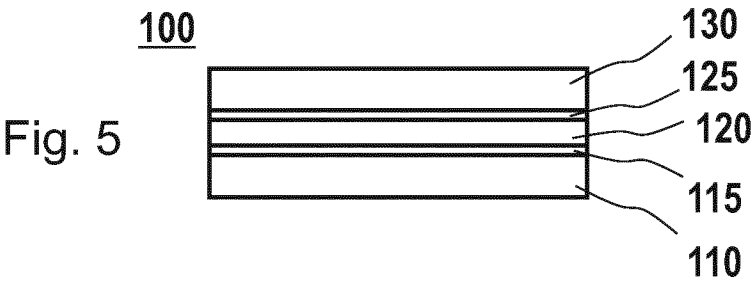
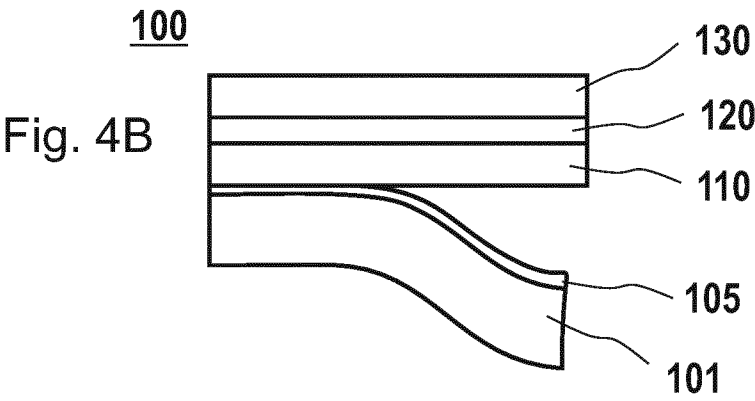
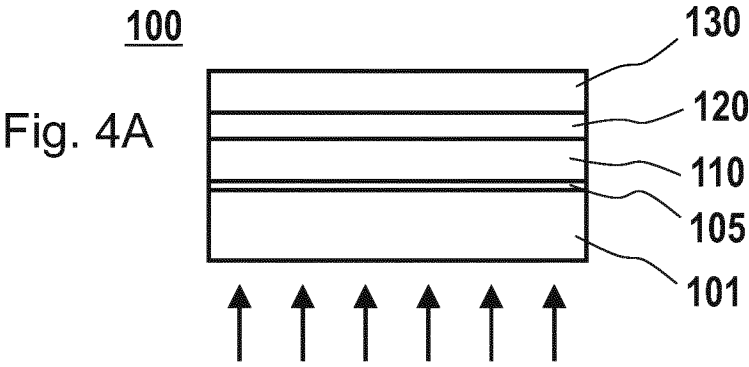
10 a third layer (130) including lithium and having a thickness of equal to or more than 5 μm and/or equal to or less 15 μm .

15. Negative electrode of claim 14, further comprising a first adhesion layer (115) between the first layer (110) and the second layer (120) and/or a second adhesion layer (125) between the second layer (120) and the third layer (130).

15







4/5

Fig. 6

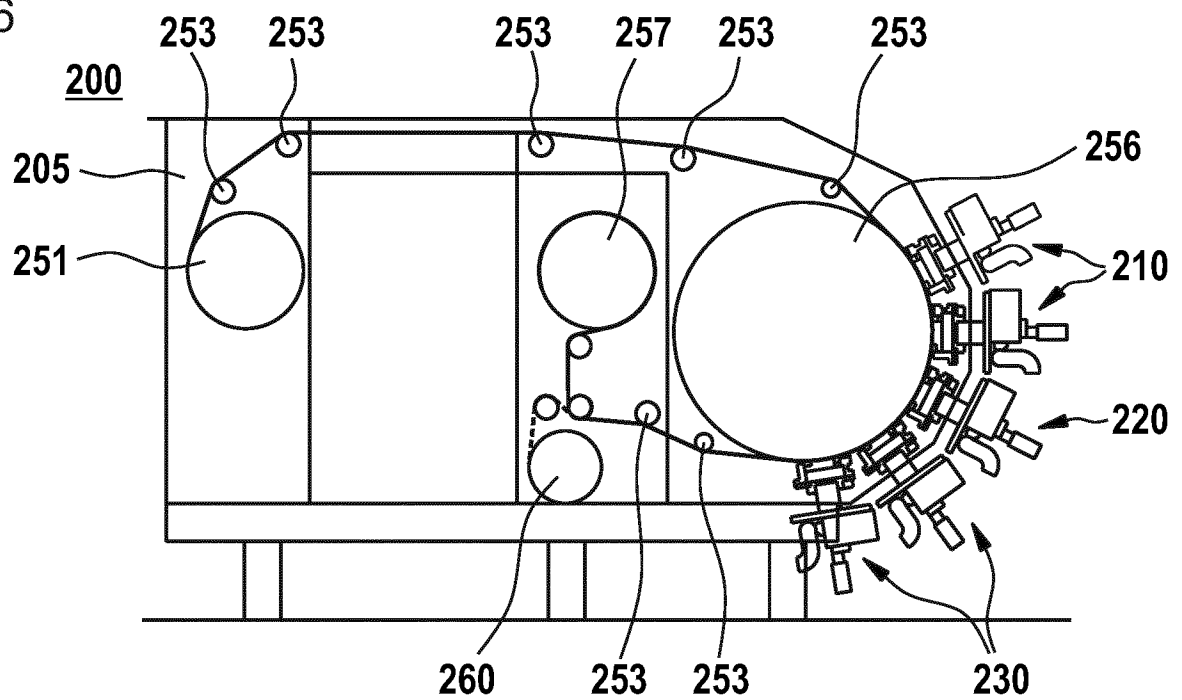
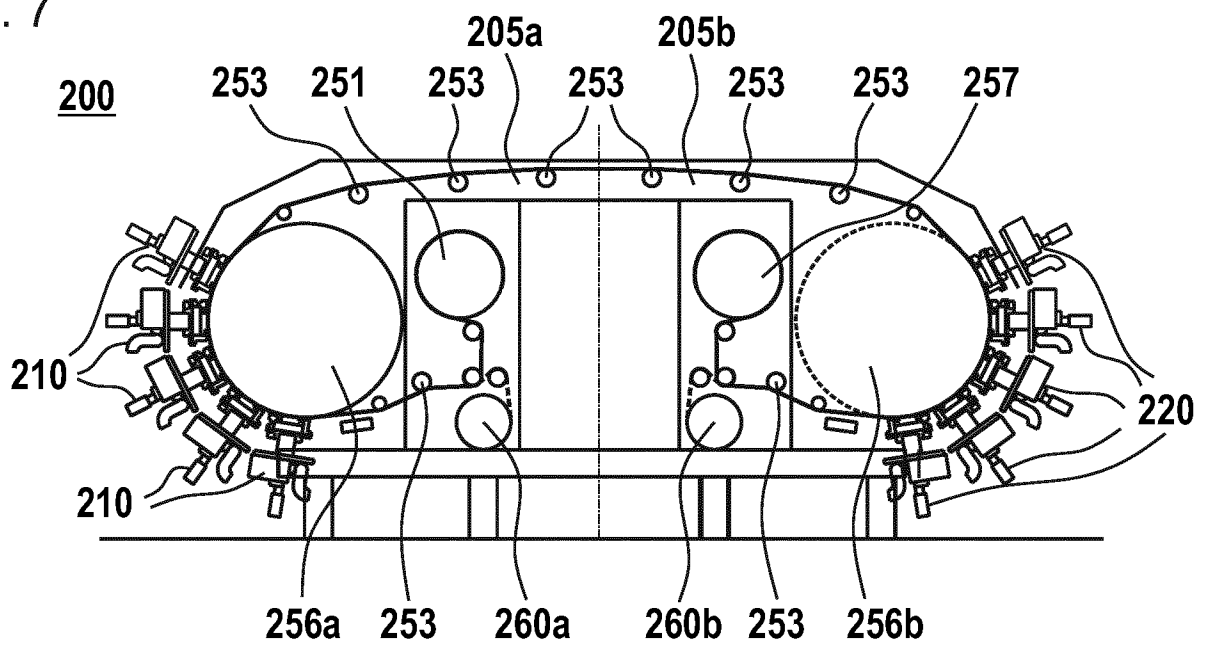
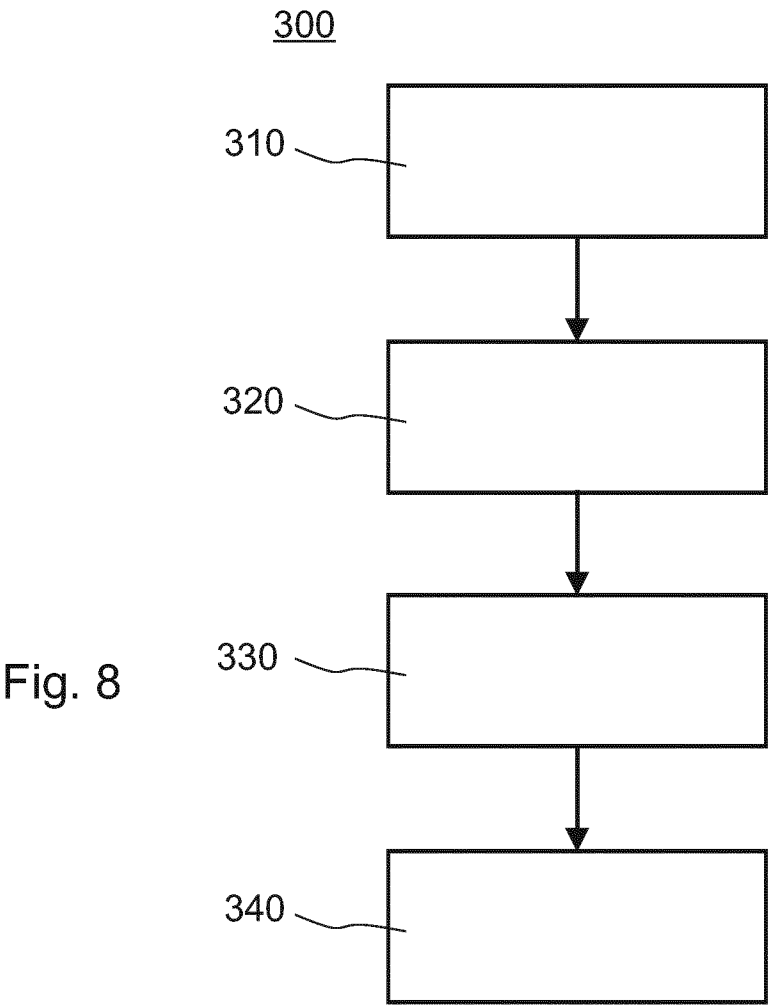


Fig. 7





INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/072864

A. CLASSIFICATION OF SUBJECT MATTER INV. C23C14/00 C23C14/56 H01M4/38 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) C23C H01M		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013/269768 A1 (SKOERELID BENGT [SE] ET AL) 17 October 2013 (2013-10-17)	1,2, 4-10,12, 13
Y A	paragraphs [0042] - [0054]; figure 1 -----	3 11
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☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 30 September 2016		Date of mailing of the international search report 07/10/2016
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Patterson, Anthony

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2015/072864

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 318 127 A (GEN VACUUM EQUIP LTD [GB]) 15 April 1998 (1998-04-15)	12
A	page 11, line 19 - page 14, line 2; figures 3,4	11,14,15
A	----- US 2014/079994 A1 (AFFINITO JOHN D [US] ET AL) 20 March 2014 (2014-03-20) paragraphs [0028], [0035] - [0038]; claims 1,24; figure 2; examples -----	11,14,15

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2015/072864

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☒ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-10, 12, 13

Method for producing a flexible layer stack consisting of at least two layers by depositing successive layers on a flexible substrate and then removing the substrate; apparatus suitable for performing the method.

2. claims: 11, 14, 15

Method for manufacturing a negative electrode for a lithium battery in addition to the negative electrode itself.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2015/072864

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