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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
28 June 2018 (28.06.2018)

(10) International Publication Number
WO 2018/116295 A1

(51) International Patent Classification:
H01M 10/052 (2010.01) *H01M 2/16* (2006.01)
H01M 2/14 (2006.01) *H01M 10/04* (2006.01)

(21) International Application Number:
PCT/IL2017/051359

(22) International Filing Date:
18 December 2017 (18.12.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/435,865 19 December 2016 (19.12.2016) US
15/431,793 14 February 2017 (14.02.2017) US
62/537,535 27 July 2017 (27.07.2017) US

(71) Applicant: STOREDOT LTD. [IL/IL]; 3 Shenkar Street, 4672503 Herzeliya (IL).

(72) Inventors: **REMIZOV, Sergey**; 3/1 Rachel HaMeshoreret Street, 4950403 Petach Tikva (IL). **BRUDNIK, Boris**; 32 Hankin Street, 3276318 Haifa (IL). **JACOB, David**; Kfar Yehoshua, 3658200 Kfar Yehoshua (IL). **ARONOV, Daniel**; 31 Rotem Street, 4201744 Netanya (IL). **PAZ, Ron**; 32/6 Shaul Tchernichovsky Street, 7656323 Rehovot (IL). **DAMTOV, Yaniv**; 1 Ben Gurion Street, 7639461 Rehovot (IL). **GOTLIB VAINSHTEIN, Ekaterina**; 26/29 Aharon Katzenelson Street, 4972139 Petah Tikva (IL).

(74) Agent: **TAL, Ophir** et al.; PEARL COHEN ZEDEK LATZER BARATZ, P.O. Box 7198, 6107121 Tel Aviv (IL).

(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ,

(54) Title: LAYER PREPARATION, TREATMENT, TRANSFER AND LAMINATION IN CELL STACK ASSEMBLY PROCESSES FOR LITHIUM ION BATTERIES

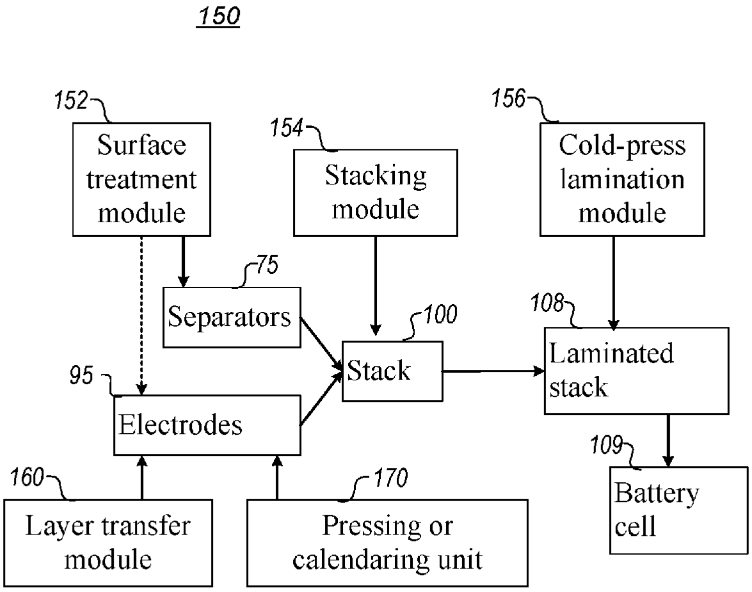


Figure 1B

(57) Abstract: Methods, stacks and electrochemical cells are provided, in which the cell separator is surface- treated prior to attachment to the electrode(s) to form binding sites on the cell separator and enhance binding thereof to the electrode(s), e.g., electrostatically. The cell separator(s) may be attached to the electrode(s) by cold press lamination, wherein the created binding sites are configured to stabilize the cold press lamination electrostatically - forming flexible and durable electrode stacks. Electrode slurry may be deposited on a sacrificial film and then attached to current collector films, avoiding unwanted interactions between materials and in particular solvents involved in the respective slurries. Dried electrode slurry layers may be pressed or calendared against each other to yield thinner, smother and more controllably porous electrodes, as well as higher throughput. The produced stacks may be used in electrochemical cells and in any other type of energy storage device.

WO 2018/116295 A1

[Continued on next page]

CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

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

Published:

— *with international search report (Art. 21(3))*

LAYER PREPARATION, TREATMENT, TRANSFER AND LAMINATION IN CELL STACK ASSEMBLY PROCESSES FOR LITHIUM ION BATTERIES

BACKGROUND OF THE INVENTION

1. TECHNICAL FIELD

[0001] The present invention relates to the field of cells in energy storage devices, and more particularly, to manufacturing of cell stacks with electrodes and to electrode production process modifications.

2. DISCUSSION OF RELATED ART

[0002] Energy storage devices can be found in an increasing number of applications, and they diversify in structure and components. Production processes of energy storage devices are complex with respect to mechanical steps and chemical considerations involved in the production. Constant demand exists for improving the performance of energy storage devices and for improving their production processes and quality of components.

SUMMARY OF THE INVENTION

[0003] The following is a simplified summary providing an initial understanding of the invention. The summary does not necessarily identify key elements nor limit the scope of the invention, but merely serves as an introduction to the following description.

[0004] One aspect of the present invention provides a method comprising surface treating the cell separator prior to attachment to at least one electrode, wherein the surface treating is configured to form binding sites on the cell separator and enhance binding thereof to the at least one electrode by creating the binding sites.

[0005] One aspect of the present invention provides a method comprising: surface treating at least one cell separator prior to attachment to at least one electrode, wherein the surface treating is configured to form binding sites on the at least one cell separator, and attaching the at least one cell separator to the at least one electrode by cold press lamination, wherein the created binding sites are configured to stabilize the cold press lamination electrostatically.

[0006] One aspect of the present invention provides a method comprising depositing an electrode slurry on a sacrificial film to form an electrode thereupon, wherein the electrode slurry comprises a first solvent, optionally surface treating the electrode, attaching (e.g., laminating) a current collector film, which is produced at least partly using a second solvent, onto the formed electrode, to yield a stack, wherein a binding strength of the electrode to the current collector film is higher than a binding strength of the electrode to the sacrificial film, and delaminating the sacrificial film from the electrode while maintaining the attachment of the electrode to the current collector film.

[0007] One aspect of the present invention provides an electrode-preparation method comprising: pressing at least two double-sided coated current collector foils between external coated foils, wherein the coatings on the double-sided foils face each other and the coatings of the respective external foils, and are pressed against each other, and preparing electrodes from at least one of the pressed double-sided coated current collector foils.

[0008] One aspect of the present invention provides a method comprising surface treating, prior to stack lamination, at least one cell separator and/or at least one electrode, wherein the surface treating is configured to form binding sites on the at least one cell separator and/or at least one electrode, respectively, and laminating, by cold press lamination, a stack of multiple alternating separators and electrodes, comprising the at least one separator and the at least one electrode, at least one of which being surface treated by said surface treating, wherein the created binding sites are configured to stabilize the cold press lamination electrostatically.

[0009] One aspect of the present invention provides an electrode-preparation method comprising: pressing at least two double-sided coated current collector foils between external coated foils, wherein the coatings on the double-sided foils face each other and the coatings of the respective external foils, and are pressed against each other, and preparing electrodes from at least one of the pressed double-sided coated current collector foils.

[0010] One aspect of the present invention provides a method comprising depositing an electrode slurry on a sacrificial film to form an electrode thereupon, wherein the electrode slurry comprises a first solvent, attaching (e.g., laminating) a current collector film, which is produced at least partly using a second solvent, onto the formed electrode, to yield a stack, wherein a binding strength of the electrode to the current collector film is higher than a binding strength of the electrode to the sacrificial film, and delaminating the sacrificial film from the electrode while maintaining the attachment of the electrode to the current collector film.

[0011] These, additional, and/or other aspects and/or advantages of the present invention are set forth in the detailed description which follows; possibly inferable from the detailed description; and/or learnable by practice of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] For a better understanding of embodiments of the invention and to show how the same may be carried into effect, reference will now be made, purely by way of example, to the accompanying drawings in which like numerals designate corresponding elements or sections throughout.

[0013] In the accompanying drawings:

[0014] Figures 1A-1C are high-level schematic illustrations of surface treating the separator in methods of stack assembly, according to some embodiments of the invention.

[0015] Figure 2 is a high-level schematic illustration of cell stacks and their assembly, according to some embodiments of the invention.

[0016] Figures 3A-3C are high-level schematic illustrations of systems and methods of preparing electrode stacks, according to some embodiments of the invention.

[0017] Figures 4A-4C are high-level schematic illustrations of derived processes for preparing various stacks using the method, according to some embodiments of the invention.

[0018] Figure 5 is a high-level schematic illustration of stacks having electrode(s) and cell separator(s) prepared by the method, according to some embodiments of the invention.

[0019] Figure 6 is a high-level schematic illustration of using structures as the current collector, which may be patterned, mesh-like and/or foam-like, according to some embodiments of the invention.

[0020] Figure 7 is a high-level flowchart illustrating methods, according to some embodiments of the invention.

[0021] Figure 8 is a high-level schematic illustration of electrode foils and an electrode production system, according to some embodiments of the invention.

[0022] Figure 9 is a high-level schematic illustration of prior art electrode production.

[0023] Figure 10 is a high-level schematic illustration of electrode production system, according to some embodiments of the invention.

[0024] Figures 11A and **11B** are high-level schematic illustrations of electrode production systems, according to some embodiments of the invention

[0025] Figures 12-16 are high-level schematic illustrations of electrode production systems, according to some embodiments of the invention.

[0026] Figures 17A and **18A** illustrate examples of cross-sections of prior art electrode foils.

[0027] Figures 17B and **18B** illustrate examples of cross-sections of electrode foils prepared according to some embodiments of the invention.

[0028] Figures 19A-19C are examples for disclosed separators and stacks prepared according to disclosed methods, compared to prior art separators and stacks.

[0029] Figure 19D is a SEM image of prior art double sided electrode (anode) produced not using the disclosed lamination process, and exhibiting rough and non-uniform anode surfaces.

[0030] Figures 20A and **20B** are SEM images of prepared laminated separators and electrodes, according to some embodiments of the invention.

[0031] Figure 21 provides SEM images of the surfaces of anodes, cathodes and separators before and after surface treatment by plasma, in a non-limiting example, according to some embodiments of the invention.

[0032] Figures 22A-22C illustrate prior art cell assembly with its cycling characteristics; and cycling characteristics of laminated stacks illustrated in **Figure 19A**, in a non-limiting example, according to some embodiments of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0033] In the following description, various aspects of the present invention are described. For purposes of explanation, specific configurations and details are set forth in order to provide a thorough understanding of the present invention. However, it will also be apparent to one skilled in the art that the present invention may be practiced without the specific details presented herein. Furthermore, well known features may have been omitted or simplified in order not to obscure the present invention. With specific reference to the drawings, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the present invention only, and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

[0034] Before at least one embodiment of the invention is explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of the components set forth in the following description or illustrated in the drawings. The invention is applicable to other embodiments that may be practiced or carried out in various ways as well as to combinations of the disclosed embodiments. Also, it is to be understood that the phraseology and terminology employed herein is for the purpose of description and should not be regarded as limiting.

[0035] Methods, stacks and electrochemical cells are provided, in which the cell separator is surface-treated prior to attachment to the electrode(s) to form binding sites on the cell separator and enhance binding thereof to the electrode(s), e.g., electrostatically, to improve contact and reduce resistance of the layers in the formed battery cell stack.

[0036] Methods, stacks and electrochemical cells are provided, in which the cell separator is surface-treated prior to attachment to the electrode(s) to form binding sites on the cell separator and enhance binding thereof to the electrode(s), e.g., electrostatically. The cell separator(s) may be attached to the electrode(s) by cold press lamination, wherein the created binding sites are configured to stabilize the cold press lamination electrostatically - forming flexible and durable electrode stacks. Electrode slurry may be deposited on a sacrificial film and then attached to current collector films, avoiding unwanted interactions between materials and in particular, solvents involved in the respective slurries. Dried electrode slurry layers may be pressed or calendared against each other to yield thinner, smother and more controllably porous electrodes, as well as higher throughput. The produced stacks may be used in electrochemical cells and in any other type of energy storage device.

[0037] Methods, stacks and electrochemical cells are provided, which improve production processes and yield flexible and durable electrode stacks. Methods comprise depositing an electrode slurry on a sacrificial film to form an electrode thereupon, wherein the electrode slurry comprises a first solvent, attaching (e.g., laminating) a current collector film, which is produced at least partly using a second solvent that may be the same or different from the first solvent, onto the formed electrode, to yield a stack, wherein a binding strength of the electrode to the current collector film is higher than a binding strength of the electrode to the sacrificial film, and delaminating the sacrificial film from the electrode while maintaining the attachment of the electrode to the current collector film. Additional layers such as a cell separator and an additional electrode may be further attached using similar steps. Surface treatment of electrodes and/or separator further enhances the cell performance. The produced stacks may be used in electrochemical cells and in any other type of energy storage device.

[0038] Certain embodiments comprise cell stacks for lithium ion batteries, which comprise multiple stacked anodes and cathodes, separated by cell separator(s), with at least one of the anodes, the cathodes and the cell separators being surface treated to form binding sites upon surfaces thereof, and with the anodes, the cathodes and the cell separators being attached by cold press lamination, which is electrostatically stabilized by the created binding sites.

[0039] Electrode-preparation methods and systems are provided, in which coated foils, e.g., having dried electrode slurry layers on one or both sides of current collector films, are pressed against each other, with coating layers on the films facing each other and pressing each other. Particularly in lithium ion battery anodes made of metalloid anode material particles, the hardness of the particles may provide more efficient pressing when pressed against each other, than when pressed by an external calendar - leading to thinner, smother and more controllably porous electrodes and higher throughput. Two or more double-sided coated current collector foils may be pressed between external (possibly sacrificial) coated foils, with the coatings on the double-sided foils face each other and face the coatings of the respective external foils. Electrodes (e.g., anodes, cathodes) may be prepared from the pressed double-sided coated current collector foils.

[0040] **Figures 1A-1C** are high-level schematic illustrations of surface treating a separator **75** in methods of stack assembly, according to some embodiments of the invention. Elements from **Figures 1A-1C** may be integrating in any of the following embodiments involving the stack's separator(s).

[0041] **Figure 1A** illustrates schematically the formation of binding sites **105A** on a separator **75**, which enhance the binding of separator **75** to electrode(s) **95** by creating bond(s) with surface elements **105B** on electrode(s) **95**, such as oxides exposed on the surface of electrode **95**, upon attachment or during the stack preparation processes. Advantageously, surface treatment **105** provides better attachment of treated surface **105A** to electrode(s) **95** than untreated surface **61** (shown schematically, the numeral **61** is used to denote untreated prior art separators), in particular for separator(s) **75** comprising polymers such as any of polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), poly vinylidene fluoride (PVDF), polymer membranes such as a polyolefin, polypropylene, or polyethylene membrane. Multi-membranes made of these materials, micro-porous films thereof, woven or non-woven fabrics etc. may be used as separator(s) **75** as well as possibly composite materials including, e.g., alumina, zirconia, titania, magnesia, silica and calcium carbonate along with various polymer components as listed above. For example, binding sites **105A** may comprise oxygen termination of surface molecules such as carboxylates, hydroxyls, etc. which may react electrostatically with oxides exposed on the surface of electrode(s) **95**, e.g., under pressure, when pressed against each other.

[0042] In certain embodiments, surface treatment **105** may be applied to one or both sides of electrode(s) **95** (e.g., anodes and/or cathodes) to form surface elements **105B** thereupon, which then bind electrostatically to binding sites **105A** on separator **75** upon cell assembly, such as upon cold pressing the stack assembly.

[0043] Figure 1B is a high-level schematic illustration of a cell stack assembly system **150**, according to some embodiments of the invention. System **150** may be used to implement any of the embodiments of the disclosed methods, and may be composed modularly from the following units, according to specifically required battery stack compositions and performance.

[0044] Cell stack assembly system **150** may comprise a surface treatment module **152** configured to treat one or both surfaces (possibly patch-wise) of each of a plurality of cell separators **75** (and possibly of electrode(s) **95**), to form binding sites thereupon; a stacking module **154** configured to stack a plurality of alternating anodes and cathodes (as electrodes **95**) between cell separators **75** to form a stack **100**; and a cold-press lamination module **156** configured to cold-press stack **100**, wherein the formed binding sites are configured to stabilize the cold-pressed stack electrostatically. Cold-press lamination module **156** is configured to press stack **100** to form a laminated stack **108** which may be used to form a battery cell **109**.

[0045] In certain embodiments, cell stack assembly system **150** may further comprise a layer transfer module **160** (see, e.g., **Figures 3A-6**) configured to prepare electrode(s) **95** attached to corresponding current collector film(s) by depositing electrode slurry on a sacrificial film to form electrode(s) **95** thereupon. The electrode slurry comprises a first solvent, the current collector film is produced using a second solvent, and is attached onto the formed electrode. The binding strength of the electrode to the current collector film is higher than a binding strength of the electrode to the sacrificial film. Layer transfer module **160** is further configured to delaminate the sacrificial film from the electrode while maintaining the attachment of the electrode to the current collector film.

[0046] In certain embodiments, cell stack assembly system **150** may further comprise a pressing or calendaring unit **170** (see, e.g., **Figures 8** and **10-18B**) comprising two pressure-applying apparatuses facing each other and configured to receive and press, against each other, at least two double-sided coated current collector foils between external coated foils. The coatings on the double-sided foils face each other and face the coatings of the respective external foils, and are pressed against each other. The two pressure-applying apparatuses are configured to apply pressure on the external coated foils to make the electrodes more uniform (with respect to electrodes press directly against the calendars. The external coated foils may also comprise electrode films (with electrode slurry coating(s)).

[0047] In various embodiments, pressing or calendaring unit **170** may be configured to operate at optimized parameters of pressure, time and optionally heat application. Pressing or calendaring unit **170** may be configured to adjust the porosity of electrode(s) **95** and in some embodiments, as part of the lamination process, attach separator(s) **75** to electrode(s) **95**, utilizing surface treatment **105** applied to separator **75** and/or electrode(s) **95** to generate stable laminated stack **108**. In certain embodiments, electrode porosity may thus be optimized during attachment in a single (pressing or calendaring) step, wherein the attachment is assisted by surface treatment **105**. It is noted that either prior art calendaring (see e.g., **Figure 9**) and/or disclosed calendaring processes according to various embodiments (see, e.g., **Figures 8** and **10-16**) may be used in embodiments of the production process, and in combination with surface treatment **105**.

[0048] **Figure 1C** illustrates schematically an example for stack assembly, utilizing rollers **106** of electrode foils (anode foil(s) **95A**, cathode foil(s) **95B**) and of separator foil(s) **75** and integrating the foils into a stack using additional rollers **107** (illustrated schematically) in various configurations – yielding stacks **100**. Stack assembly processes, into which separator surface treatment may be integrated, comprise any of the following - single sheet stacking, winding, Z-folding with single electrodes, Z-folding with electrode rolls, and so forth, as explained in more details below. Surface treatment **105** may be applied to either side of separator patches or foils, continuously or intermittently, depending on the spatial relations of the respective side of separator **75** with electrode **95** it is designed to bind, e.g., anode **95A**. Stack assembly may be carried out in electrode production system(s) **150**, possibly comprising electrode and stack preparation systems and methods, and possibly pressure-applying apparatuses as disclosed below.

[0049] Certain embodiments comprise methods **200** disclosed below, stack assembly systems **150** and/or laminated stacks **108**, comprising surface treating **105**, prior to stack lamination, at least one cell separator **75** and/or at least one electrode **95**, wherein surface treating **105** is configured to form binding sites on the at least one cell separator and/or at least one electrode, respectively, and laminating, by cold press lamination, a stack of multiple alternating separators and electrodes, comprising the at least one separator and the at least one electrode, at least one of which being surface treated by surface treating **105**, wherein the created binding sites are configured to stabilize the cold press lamination electrostatically. The alternating separators and electrodes may be attached by any stack assembly process, such as single sheet stacking, winding, Z-folding with single electrodes and/or Z-folding with electrode rolls, and the surface treatment may be carried out by any of plasma treatment, corona treatment, ultraviolet radiation. The stack of multiple alternating separators and electrodes may comprise any of: a single separator and a single electrode, a single separator and two electrodes on either side thereof, a single electrode and two separators on either side thereof and/or an alternating plurality of separators and plurality of electrodes. In a non-limiting example, the stack of multiple alternating separators and electrodes may comprise a single separator foil and two electrodes foils which are laminated to on either side of the separator foil by a roll to roll process.

[0050] **Figure 2** is a high-level schematic illustration of cell stacks **100** and their assembly, according to some embodiments of the invention. **Figure 2** illustrates schematically cell stack **100** in exploded view and, correspondingly, the structure of laminated stack **108** after cold-press lamination **156** (illustrated schematically by arrows). Optional processes of applying optional coatings **82**, **92** and **77** to electrodes **95** (anodes **95A**, cathodes **95B** and corresponding current collectors **80A**, **80B**) (see **Figures 3A-6** and corresponding description below), layer transferring **160** (e.g., by corresponding module **160**), pressing or calendaring **170** (of one-another-facing electrodes, e.g., by corresponding unit **170**) may be part of the stack assembly. The dotted arrow indicates the optional stacking of multiple sets of separators **75** and electrodes **95** to form stack **100**.

[0051] In certain embodiments, multiple separators **75** and corresponding multiple alternating anodes and cathodes may be assembled into cell stack **100**. In various embodiments, both the anode(s) and the cathode(s) may be attached to separator(s) **75** simultaneously by the cold pressing. The cold-press lamination may be carried out below any of 60°C (e.g., as in the example below, at 55°C), 50°C, 40°C and/or at room temperature, and surface treatment **105** may be carried out (be surface treating unit **152**) by any of plasma treatment, corona treatment, ultraviolet radiation and/or possibly by depositing an ionic-conductive surface layer to form binding sites **105A**.

[0052] In certain embodiments, cell separator(s) **75** may be polymeric (as disclosed above) and surface treatment **105** may comprise depositing a ceramic surface layer onto polymeric cell separator **75**. As illustrated schematically in **Figure 2**, surface treatment **105** may be configured to modify only treated surface **75A** while maintaining the bulk properties of separator(s) **75** such as ionic conductivity of bulk **75B** of separator(s) **75**, possibly flexibility of separator(s) **75**, interaction properties with the electrolyte etc. Treated surface **75A** may be porous and ion-conductive, to maintain and/or enhance the performance of cell stack **108**. Cold-press lamination **156** may be configured to ensure close contact between separator(s) **75** and electrode(s) **95**.

[0053] Lamination of separator(s) **75** and electrode(s) **95** may be configured to reduce the resistance of laminated cell stack **108** and battery **109** with respect to prior art stack assembly methods, due to the close contact between separator(s) **75** and electrode(s) **95**, based on the disclosed electrostatic binding. In certain embodiments, laminated cell stack **108** and battery **109** may be advantageous in fast charging applications, in which lower resistance is of particular advantage. Examples for fast charging applications comprise battery cells **109** configured to operate and high charging and/or discharging rates such as e.g., at least at a maximal charging and/or discharging rate of e.g., 5C, or possibly 10C or 50C, or higher, with the C rate, or C ratio, being the charging or discharging current divided by the capacity.

[0054] Any of the disclosed systems and methods may be applied to anodes having Si (silicon), Ge (germanium), Sn (tin) and/or LTO (lithium titanium oxide, lithium titanate) -based anode active material and/or possibly carbon-based anode material such as graphite and/or graphene. The disclosed systems and methods may be applied to cathodes comprise materials based on layered, spinel and/or olivine frameworks, having various compositions, such as LCO formulations (based on $LiCoO_2$), NMC formulations (based on lithium nickel-manganese-cobalt), NCA formulations (based on lithium nickel cobalt aluminum oxides), LMO formulations (based on $LiMn_2O_4$), LMN formulations (based on lithium manganese-nickel oxides), LFP formulations (based on $LiFePO_4$), lithium rich cathodes, and/or combinations thereof. The disclosed systems and methods may be applied to electrolyte comprising liquid electrolytes such as ethylene carbonate (EC), diethyl carbonate (DEC), propylene carbonate (PC), fluoroethylene carbonate (FEC), ethyl methyl carbonate (EMC), dimethyl carbonate (DMC), vinylene carbonate (VC), possibly tetrahydrofuran (THF) and/or its derivatives, and combinations thereof and/or solid electrolytes such as polymeric electrolytes such as polyethylene oxide, fluorine-containing polymers and copolymers (e.g., polytetrafluoroethylene), and combinations thereof. The electrolyte(s) may comprise lithium electrolyte salt(s) such as $LiPF_6$, $LiBF_4$, lithium bis(oxalato)borate, $LiN(CF_3SO_2)_2$, $LiN(C_2F_5SO_2)_2$, $LiAsF_6$, $LiC(CF_3SO_2)_3$, $LiClO_4$, LiTFSI, $LiB(C_2O_4)_2$, $LiBF_2(C_2O_4)$, tris(trimethylsilyl)phosphite (TMSP) and combinations thereof. Electrolyte additive(s) (e.g., at few %wt) may comprise tris(trimethylsilyl)phosphite (TMSP), tris (trimethylsilyl) borate (TMSB), lithium difluoro(oxalato)borate (LiFOB), succinic anhydride, trimethyl phosphate (TMP) and triphenyl phosphate (TFP), fluorinated solvents (methyl nonafluorobutyl ether (MFE), and combinations thereof.

[0055] **Figures 3A-3C** and **4A-4C** are high-level schematic illustrations of system **160** and method **200** of preparing electrode stacks **100**, according to some embodiments of the invention. Elements from **Figures 3A-3C** and **4A-4C** may be combined in any operable combination and the illustration of certain elements in certain figures and not in others merely serves an explanatory purpose and is non-limiting. Layer transferring may be carried out by layer transfer module **160** of cell stack assembly system **150**.

[0056] **Figures 3A-3C** exemplify schematically the attachment of respective electrodes **95**, namely an anode **95A** and a cathode **95B**, to respective current collector films **80**, namely a copper (Cu) film **80A** and an aluminum (Al) film **80B**, respectively. Electrodes **95A**, **95B** (**Figure 3A**) may first be formed on respective sacrificial films **90**, namely a copper foil **90A** and aluminum foil **90B**, respectively, from respective electrode slurries involving certain solvents. Then, electrodes **95** on sacrificial films **90** are attached (**220**) to the corresponding current collector films **80** and sacrificial films **90** are delaminated (**222**) to yield respective stacks **100**, namely anode-current collector stack **100A** and cathode-current collector stack **100B**, respectively. In certain embodiments, respective coatings **82**, such as carbon and/or binder layers **82A**, **82B** may be applied to current collector films **80** prior to attachment **220** to enhance binding and/or improve the stack's operation. The binding strength of electrode **95** to current collector film **80** (with or without coating **82**) is configured to be higher than the binding strength of electrode **95** to sacrificial film **90**. In certain embodiments, layer **82** may comprise a thin carbon coating (e.g., ~1μm thick) or a conductive adhesive. **Figures 3B** and **3C** illustrate additional attachment modes disclosed below. Elements shown separately in **Figures 3A-3C**, and in other figures, may be combined to form various embodiments of the disclosed invention.

[0057] The inventors have found out that direct application of the electrode slurry on the current collector film often results in interactions between the solvents used to form the electrode slurry and solvents which were used in production of the current collector film and/or degradation of current collector **80** due to solvent ingredients. Even though these interactions may be useful for the enhancement of binding strength between the current collector and the electrode coating, these interactions, if excessive, may deteriorate the performance of the respective prior art electrodes and the prior art cells having these electrodes. Furthermore, during and after the electrode slurry application onto the current collector in the prior art, problems related to the poor wettability of the current collector by the electrode slurry may arise. These problems may result in coating defects and poor adhesion of the resulting coating to the current collector. However, the inventors have found out that forming the electrode of the sacrificial film and then transferring the electrode as disclosed herein to the current collector film solve these problems and provide flexible electrode stacks with improved performance. Moreover, disclosed embodiments may provide sufficient binding strength between the current collector and the electrode coating.

[0058] In certain embodiments, the surface of one or more of electrodes **95** (e.g., anode **95A**, cathode **95B**) may be pretreated **105** to enhance its adhesion to current collector film **80** (with or without coating **82**). In certain embodiments, with uncoated current collector film **80**, the surface of one or more of current collector film **80** (e.g., Cu film **80A** or Al film **80B**) may be pretreated **105** to enhance its adhesion to respective electrode(s) **95**. In certain embodiments, coated films may also be pre-treated to enhance the respective binding to adjacent layer. Achieved adhesion enhancement may improve the integration of the respective layer and provide more uniform and compact cell structures, resulting in improved electrolyte wetting, cell conductivity (e.g., reduce ESR - equivalent series resistance) and other cell characteristics. For example, plasma treatment **105** may be applied to activate the respective surface(s) prior to pressing the respective layers, to enhance their attachment (e.g., lamination) by resulting electrostatic forces between the activated surface and the layer connected thereto. Surface treatment **105**, such as by plasma, may be configured to affect only the surface and not deteriorating the bulk properties of the treated layer, and may additionally improve wetting and ionic conductivity of the treated surface.

[0059] The electrode slurry may comprise a water or organic solvent, active material(s), conductive agent(s) and/or binder(s), and be dried, e.g., by evaporation of the solvent, to form electrode **95** on sacrificial film **90** prior to its attachment to current collector **80**. Attachment **220** may be carried out by bringing electrode **95** into close contact with current collector **80** which may be coated by an adhesive conductive layer coating facing electrode **95**. As the surface of current collector **80** may be undesirably altered by an excessive interaction with the solvent of the electrode slurry, allowing the solvent to at least partially evaporate prior to the attachment prevents or at least significantly reduces such an excessive interaction. The attachment may be carried out in a lamination process. Sacrificial film **90** may be delaminated **222** from electrode **95** after attachment **220**, e.g., by peeling it off the electrode, leaving behind stack **100** with current collector **80** attached to electrode **95**, which exhibits highly improved adhesion, cohesion and flexibility.

[0060] Method **200** enables fabrication of mechanically strong and flexible electrodes for energy storage devices. Advantageously, disclosed method **200** provides any of the following: improved adhesion (bonding of electrode **95** to current collector **80**), improved cohesion (e.g., in electrode **95**, bonding between active material, conductive additive particles and binder), improved flexibility of electrode **95**, decreased binder content in electrode **95**, and method **200** prevents the undesirable interaction of current collector **80** and/or adhesive layer **82** with slurry solvents, thus preventing the wettability issues or corrosion of current collector **80** which are typical in the prior art.

[0061] Advantageously, method **200** may be configured to further enable mitigation and/or avoid wettability problems as compared with the direct coating of the electrode slurry onto the current collector, carried out in the prior art. For example, common prior art practice is to use NMP (N-methyl-2-pyrrolidone) as the solvent in the electrode slurry, however NMP may attack carbon coating **82** on current collector film **80** until the slurry has dried. As a result, carbon coating **82** may not function properly.

[0062] As the risk of solvent influence on current collector **80** is reduced, selection and optimization of active materials, binders and conductive agents in the electrode slurry may be carried out to a larger extent. The formulation of the slurry may be selected to ensure the optimized packing density and related porosity of electrode **95** to provide optimal energy and power density of the energy storage device.

[0063] Sacrificial film **90** may comprise a metal foil and/or a polymeric foil or film. Sacrificial film **90** may comprise an anti-adhesive coating **92** that makes the transfer process easy. In particular, coating **92** (and/or coating **82**) may be selected so that the binding strength of electrode **95** to current collector film **80** (possibly via coating **82**) is higher than the binding strength of electrode **95** to sacrificial film **90** (possibly via coating **92**), as indicated schematically in **Figure 3B**.

[0064] Current collector film **80** may be made of various materials (e.g., copper or aluminum) and may be formed as a foil, a film, a grid or any other configuration. Coating **82** may be an adhesive conductive coating, such as a mixture of conductive particles (for example, carbon black, graphite, graphene or metal particles) and polymeric binder (for example, PVDF (polyvinylidene difluoride), PTFE (polytetrafluoroethylene), acrylic resins, elastomers, water-soluble polymers and the likes). At least one of the binders used in the electrode slurry and in the adhesive coating may be configured to increase the adhesiveness between electrode **95** and current collector film **80**, in certain embodiments, under influence of temperature and/or pressure during attachment (e.g., lamination) stage **220** and possibly in delamination **222** stage, due to, for example, thermoplastic properties of the respective binder polymer. In certain embodiments, surfaces of electrode **95** and/or current collector film **80** and/or coating **82** may be wetted by an appropriate solvent to increase adhesive property, transferability and/or conformability. **Figure 3C** illustrates schematically the optional wetting **91** of the interface between electrode **95** and sacrificial film **90** (possibly as a residual solvent from the electrode slurry), wetting **96** of electrode **95** and/or wetting **81** of current collector film **80** and/or coating **82**.

[0065] Attachment **220** may be carried out by lamination, e.g., by hot roll press, followed by separation of respective copper or aluminum foils **90A**, **90B** respectively as delamination **222**.

[0066] The following are more detailed examples for preparing anode stack **100A** and cathode stack **100B**. Anode stack **100A** was prepared from a water-based anode slurry comprising carbon/tin composite as the active material, carbon black as the conductive agent and CMC (carboxymethyl cellulose) as the binder onto a copper foil substrate as sacrificial film **90**. The thickness was controlled by using a doctor blade with 50μm, **100**μm and **120**μm gaps. Coated samples were dried in a convection oven for one hour at **80**°C to evaporate the solvent and form electrode **95** on copper sacrificial film **90**. In a tape test using an adhesive tape, a significant portion of the coating (electrode **95**) was removed with the tape, as a simulator for current collector film **80**. After the coated samples were crumpled, electrode coating flaked off (delaminated) from the copper substrate. For preparation of stack **100A**, a commercial copper substrate with carbon coating was used as current collector film **80** and carbon/tin electrode was attached to carbon coating **92**. The sandwiched sample was passed through a gap between a pair of stainless steel rolls heated up to **120**°C for attachment **220**. After cooling down to room temperature, stack **100A** was disassembled. Electrode **95**, which initially was on copper sacrificial film **90** prior to the hot pressing, was transferred onto carbon coated substrate **80**. Using the tape test, it was found that electrode **95** was firmly attached to carbon coated substrate **80**. Over time, no crumpling or damage of electrode **95** were observed and no delamination was shown, illustrating the stability and flexibility of stack **100A**.

[0067] Similarly, cathode stacks **100B** may be produced using an electrode slurry containing $LiCoO_2$ as an active material, CMC as the binder, carbon black as the conductive additive and water as the solvent. The cathode slurry was coated onto a 15 micron-thick aluminum foil as sacrificial film **90** and dried at 80°C to produce cathode **95**. Cathode **95** was then transferred to a commercial aluminum foil used as current collector film **80** having carbon coating **82** on the both sides of the foil using hot roll press heated up to 80°C. In certain embodiments, anodes **100A** and cathodes **100B** produced as disclosed herein may exhibit impoved mechanical stability.

[0068] Figures 4A-4C are high-level schematic illustrations of processes for preparing various stacks **100** using method **200**, according to some embodiments of the invention. **Figure 4A** illustrates schematically the preparation of two stacks **100** simultaneously by applying electrode slurry to both sides of sacrificial film **90** to produce electrodes **95** on both sides thereof and then attaching current collector films **80** (possibly with coatings **82**) to both electrodes **95** simultaneously. Delamination **222** may be synchronous or sequential to yield stacks **100**. **Figure 4B** illustrates schematically a similar double-sided preparation with (···) indicating possible additional layers attached on the other sides of current collector films **80** (possibly with coatings **82**), possibly with additional cell components. **Figure 4C** illustrates schematically simultaneous production of two double-sided stacks **100**, each having current collector films **80** (possibly with coatings **82**) with electrodes **95** on either side thereof. It is noted that in any of the illustrations, current collector films **80**, coatings **82**, electrodes **95** and sacrificial films **90** may be of different kinds in a single process, as long as the relations in binding strength illustrated in **Figures 3B**, **3C** are maintained.

[0069] In certain embodiments, the surface of one or more of electrodes **95** and/or current collector film **80** (when not coated) may be pretreated **105** to enhance its adhesion to respective adjacent current collector film **80** and/or electrode **95**. In certain embodiments, coated films may also be pre-treated to enhance the respective binding to adjacent layer. Achieved adhesion enhancement may improve the integration of the respective layer and provide more uniform and compact cell structures, resulting in improved electrolyte wetting, cell conductivity (e.g., reduce ESR - equivalent series resistance) and other cell characteristics. For example, plasma treatment **105** may be applied to activate the respective surface(s) prior to pressing the respective layers, to enhance their attachment (e.g., lamination) by resulting electrostatic forces between the activated surface and the layer connected thereto. Surface treatment **105**, such as by plasma, may be configured to affect only the surface and not deteriorating the bulk properties of the treated layer, and may additionally improve wetting and ionic conductivity of the treated surface.

[0070] Figure 5 is a high-level schematic illustration of stacks **100** having electrode(s) and cell separator(s) **75**, prepared by method **200**, according to some embodiments of the invention. **Figure 5** is a highly schematic illustration of multi-stage method **200**, which may be implemented with different variations to produce various stacks **100**. Layer transferring may be carried out by layer transfer module **160** of cell stack assembly system **150**. The term "cell separator" refers to a separator film in an electrochemical cell or in any other type of energy storage device. For example, separator(s) may comprise various materials, such as any of polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), poly vinylidene fluoride (PVDF) and/or other appropriate materials. As non-limiting examples, a polymer membrane such as a polyolefin, polypropylene, or polyethylene membrane, a multi-membrane thereof, a micro-porous film, or a woven or non-woven fabric may be used as the separator. In certain embodiments, composite separators may be prepared from combinations of alumina, zirconia, titania, magnesia, silica and calcium carbonate along with various polymer components as listed above.

[0071] Following attachment **220** of electrode **95** to current collector film **80** and delamination **222** of sacrificial film **90** (with respective binding strengths (2)>(1)) to form and intermediate stack **100C**, as illustrated schematically in **Figures 3A-3C**, a cell separator slurry (prepared using a third solvent which may attack electrode **95** and/or a coating **77** attached thereto if brought in direct contact with the cell separator slurry) may be spread onto a sacrificial film **70** and dried thereupon (e.g., by evaporation) to form cell separator **75**. Possibly a coating **72** may be applied to sacrificial film **70** prior to the deposition of the cell separator slurry to regulate the binding strength (3) there between, and possibly coating **77** may be applied to electrode **95**. At an attachment stage **260**, cell separator **75** may be attached to electrode **95** and sacrificial film **70** may then be delaminated **280** to form stack **100** with current collector film **80**, electrode **95** and cell separator **75**, possibly with coatings **82**, **77** which regulate conductivity and adhesiveness between the layers of stack **100**. In particular, the binding strengths (2), (4) between layers of stack **100** are higher that binding strength (3) between cell separator **75** and sacrificial film **70** (and/or its coating **72**) to maintain the stack structure through the attachment and delamination processes. Attachment and delamination processes **220**, **260** and **222**, **280** respectively, may be configured to enhance these differences in binding strengths, e.g., increase binding strengths (2), (4) and/or reduce binding strengths (1), (3). Application of pressure and possibly heat may be configured accordingly.

[0072] In certain embodiments, the surface of separator **75** (and/or possibly of respective electrode **95** if not coated) may be pretreated **105** to enhance its adhesion to respective adjacent electrode **95**. Separator pretreatment **105** may be similar or different from electrode or current collector film pretreatment **105**. In certain embodiments, coated films may also be pre-treated to enhance the respective binding to adjacent layer. Achieved adhesion enhancement may improve the integration of the respective layer and provide more uniform and compact cell structures, resulting in improved electrolyte wetting, cell conductivity (e.g., reduce ESR - equivalent series resistance) and other cell characteristics. For example, plasma treatment **105** may be applied to activate the respective surface(s) prior to pressing the respective layers, to enhance their attachment (e.g., lamination) by resulting electrostatic forces between the activated surface and the layer connected thereto. Surface treatment **105**, such as by plasma, may be configured to affect only the surface and not deteriorate the bulk properties of the treated layer, and may additionally improve wetting and ionic conductivity of the treated surface. It is emphasized that disclosed surface treatment **105** is configured to enhance the lamination of the layers and the compactness of the resulting structure, as disclosed herein.

[0073] In certain embodiments, surface treatment **105** of separator **75** may be configured to create oxygen termination of surface molecules such as carboxylates, hydroxyls, etc. which may react electrostatically with oxides exposed on the surface of electrode(s) **95** (e.g., anode **95A**, cathode **95B**) under pressure, when pressed against each other. Consequently, improved integration (or lamination) of separator **75** and electrode(s) **95** may be achieved.

[0074] Surface treatment **105** of separator **75** may be carried out using various technologies, such as plasma, corona, ultraviolet radiation (UV) etc. Surface treatment **105** may be applied a specified period prior to attachment of separator **75** and electrode(s) **95**, which is configured to maintain the required activation of the surface of separator **75**, e.g., maintain its electrostatic activation, a required density of oxygen termini etc.

[0075] In certain embodiments, exposed surface features of electrode(s) **95** may suffice to bind the treated surface of separator **75**, e.g., due to defects and/or due to characteristics of the anode active material. In other embodiments, the surface of electrode(s) **95** may be treated to providing binding sites to the treated surface of separator **75**. In certain embodiments, the anode active material may comprise metalloids such as silicon, germanium and/or tin and separator **75** may comprise compatible materials such as silica or equivalent oxides, to enhance the binding capacity of surface-treated separator **75** to electrode(s) **95**.

[0076] Surface treatment **105** of separator **75** may be incorporated in a range of cell assembly and stacking techniques, implementing any of winding, stacking and folding of electrodes **95** and separator **75**, such as e.g., single sheet stacking (attaching discrete electrodes **95** and separator **75** elements), winding (attaching electrodes **95** and separator **75** in foils, using two separator rolls to fully fold the anodes and cathodes into the stack), Z-folding with single electrodes (discrete electrodes **95** folded into separator **75** foil, with separator **75** contacting the anodes at alternating faces thereof), Z-folding with electrode rolls, etc. Surface treatment **105** of separator **75** may be configured and applied to one or both sides of separator **75** and/or possibly at patches thereof configured to be attached to the anodes and/or to the cathodes, depending on the respective stack assembly process.

[0077] Advantageously, in certain embodiments, lamination of lithium battery electrodes to standard separators utilizing surface activation treatments on the separators may be applied without using adhesion promoters to avoid closing pores in the attached surfaces and thereby avoid increasing the cell resistance. Surface treatment may also be utilized to enhance surface wetting by the electrolyte. Using surface treatment to enhance lamination by utilizing electrostatic forces between surface anchoring groups on separator **75** and electrodes **95** may significantly improve cell integration and compactness, while maintaining low cell resistance.

[0078] Method **200** may further comprise attaching a second electrode, possibly attached to another current collector film (not shown) to cell separator **70** along similar process steps as illustrated in **Figure 5**, to produce stack **100** having an anode and a cathode, each with the corresponding current collector film, separated by a cell separator. Such stack **100** may then be used directly to form the electrochemical cell or energy storage device cell.

[0079] **Figure 6** is a high-level schematic illustration of using structures **80C** as current collector **80**, which may be patterned, mesh-like and/or foam-like according to some embodiments of the invention. Structures **80C** may be applicable as any type of current collector **80**, **80A**, **80B**. Structures **80C** may be patterned in various patterns, comprise a mesh or be mesh-like, comprise a foam or be foam-like, and so forth (two non-limiting examples, mesh and pattern/foam are illustrated schematically in **Figure 6**). In some embodiments, structures **80C** may be used as current collector **80**, with the pitch, or characteristic size, and the electrode thickness being optimized for the transfer mechanism described above.

[0080] **Figure 6** further illustrates schematically various configurations for using structures **80C** to produce, e.g., one sided electrodes **95** with variable thickness (T1, T2) or uniform thickness (T1) on structures **80C**, and two-sided electrodes **95** with variable thickness (T1, T3) or uniform thickness (for T1=T3) on structures **80C**.

[0081] Method **200** may further comprise using structures which are patterned, mesh-like and/or foam-like for the current collector (stage **216**, in **Figure 7**), illustrated in **Figure 6** as optionally starting from a uniform structure **80** and/or optionally applying coating **82** as described above. In certain embodiments, uniform structure **80** may be patterned or otherwise modified (e.g., mechanically or chemically) to provide structures **80C**. Electrode **95** may then be coated e.g., by coating **77** and be further processed (e.g., mechanically or chemically, such as by etching), possibly involving additional deposition and transfer steps to form stack **100**.

[0082] Advantageously, using patterned, mesh-like and/or foam-like structures **80C** may improve the access of ions to electrode **95** through open vias provided by structures **80C**, possibly to both sides of electrode **95**. Patterned, mesh-like and/or foam-like structures **80C** may be particularly advantageous in high specific energy thin layer electrodes **95** (e.g., having thickness, e.g., T1, T2 and/or T3 of any of 10μm, 20μm, 50μm, **100**μm, **200**μm, etc.).

[0083] In some embodiments, structures **80C** may be used either directly as current collector **80** and/or as sacrificial film **70** for transferring electrodes **95**.

[0084] In some embodiments, method **200** may be used to coat an adhesion layer in a similar manner as described for electrode **95**. Particular advantages of method **200** in case of the adhesion layer result from the very small thickness of the adhesion layer, which impedes application of the adhesion layer in the prior art.

[0085] Certain embodiments comprise stacks **100** described herein, as produced by method **200**, and electrochemical cells comprising stacks **100**. Elements from **Figures 1-6** may be combined in any operable combination, and the illustration of certain elements in certain figures and not in others merely serves an explanatory purpose and is non-limiting.

[0086] **Figure 7** is a high-level flowchart illustrating methods **200**, according to some embodiments of the invention. The method stages may be carried out with respect to stacks **100** described above, which may optionally be configured to implement method **200**. The stages of method **200** may be implemented irrespective of their order.

[0087] In certain embodiments, method **200** may comprise surface treating the cell separator prior to attachment to at least one electrode (stage **180**), and configuring the surface treatment to form binding sites on the cell separator and enhance, electrostatically, the binding thereof to the electrode(s), through the binding sites (stage **184**). For example, surface treatment **105** may comprise any of plasma, corona, UV radiation, and/or deposition or sputtering processes (stage **182**). Surface treatment **105** may be applied on one or both sides of the cell separator(s) (stage **186**). For example, the cold press lamination is carried out below 50°C.

[0088] In certain embodiments, method **200** may further comprise attaching anode(s) and cathode(s) to opposite sides of the separator, simultaneously (stage **190**), assembling cell stack(s) by multiple cell separators, which may be surface-treated on both sides, to corresponding multiple alternating anodes and cathodes (stage **192**) and attaching the electrode(s) to the separator(s) by cold-press lamination, utilizing the electrostatic binding sites to stabilize the stack (stage **194**). In certain embodiments, method **200** may comprise carrying out the stack assembly by any of single sheet stacking, winding, Z-folding with single electrodes and/or Z-folding with electrode rolls (stage **196**).

[0089] In various embodiments, method **200** may further comprise integrating any of separator and/or electrodes surface treatment and cold-press lamination, layer transfer(s) from sacrificial film(s) and face-to-face pressing of anodes into stack production (stage **205**).

[0090] Method **200** comprises depositing an electrode slurry (comprising a first solvent) on a sacrificial film to form an electrode thereupon (stage **210**), attaching (e.g., laminating) a current collector film (which is produced at least partly using a second solvent) onto the formed electrode to yield a stack (stage **220**). Any of the components are configured so that the binding strength of the electrode to the current collector film is higher than the binding strength of the electrode to the sacrificial film (stage **221**). Method **200** may further comprise applying at least a pressure on the stack to carry out the lamination (and possibly the delamination) (stage **224**), e.g., by pressing or calendaring, optionally also applying heat to carry out the lamination to enhance the binding strength of the cell separator to the electrode. Method **200** further comprises delaminating the sacrificial film from the electrode while maintaining the attachment of the electrode to the current collector film (stage **222**).

[0091] Method **200** may comprise, e.g., as implementations of stage **221**, any of coating the current collector film with a conductive adhesive prior to attaching **220** and/or surface treating the current collector film prior to attaching **220** (stage **212**); coating the electrode with a conductive adhesive such as a carbon coating prior to attaching **220** and/or surface treating the electrode prior to attaching **220** (stage **214**); and/or coating the sacrificial film, prior to depositing **210**, with a coating having a lower binding strength to the electrode than the binding strength of the electrode to the current collector film (stage **218**). In certain embodiments, method **200** further comprises pretreating at least one side of the electrode (stage **218**).

[0092] Method **200** may optionally further comprise applying at least a pressure on the stack produced after delamination stage **222** e.g., by pressing or calendaring, optionally also applying heat and configuring the applied pressure (and optionally heat) to enhance the binding strength of the cell separator to the electrode (stage **225**). In certain embodiments, method **200** may comprise wetting at least one of the electrode and the current collector film to enhance adhesiveness therebetween (stage **228**).

[0093] In certain embodiments, disclosed methods, stacks and electrochemical cells implementing any of surface-treated separators, layer transferring using sacrificial films and/or face-to-face calendaring of the electrode material may be combined and integrated to yield flexible and durable electrode stacks.

[0094] **Figure 7** further illustrates a non-limiting example for an electrode production method **200A** as part of method **200** disclosed herein, according to some embodiments of the invention. The method stages may be carried out with respect to electrode production system **150** and/or electrodes **95** described above, which may optionally be configured to implement method **200A**. Method **200A** may comprise stages for producing, preparing and/or using electrode production system **150** and/or electrodes **95**, such as any of the following stages, irrespective of their order.

[0095] In certain embodiments, method **200** may comprise preparing electrode foils by pressing (e.g., calendaring) two coated films (e.g., having coatings of dried electrode slurry), with the coatings on the films facing each other and pressing each other (stage **230**). Method **200** may comprise configuring the electrode production system to press pairs of coated electrode foils against each other, so that the coatings (e.g., dried electrode slurries) apply forces on each other (stage **232**).

[0096] In certain embodiments, pressing **210** may be configured to enable and/or cause mass transfer between protrusions and cavities in the film coatings (e.g., of the dried electrode slurry layers) to even out surfaces thereof (stage **234**).

[0097] Certain embodiments comprise pressing at least two double-sided coated current collector foils between external coated foils, wherein the coatings on the double-sided foils face each other and face the coatings of the respective external foils, and are pressed against each other (stage **240**). In certain embodiments, the external foils may be disposable and/or be used as sacrificial layers.

[0098] In certain embodiments, pressing **210** may be carried out rotationally by calendaring and/or linearly, e.g., by linear pressing (stage **242**). In certain embodiments, method **200** may further comprise applying heat to at least one of the foils during the pressing (stage **244**).

[0099] In certain embodiments, method **200** comprises preparing electrodes from at least one of the pressed double-sided coated current collector foils and/or comprises preparing electrodes from at least one of the pressed single-sided coated current collector foils (stage **246**).

[00100] Certain embodiments comprise anode(s) prepared by electrode-preparation method **200** and/or electrode production system **150**; cathode(s) prepared by electrode-preparation method **200** and/or electrode production system **150**; and/or lithium ion cell(s) comprising anode(s) and/or cathode(s) prepared by electrode-preparation method **200** and/or electrode production system **150**.

[00101] Method **200** may comprise consecutively, depositing a cell separator slurry on a second sacrificial film to form a cell separator thereupon (stage **250**), attaching (e.g., laminating) the electrode (which is attached to the current collector film) onto the formed cell separator, to yield a second stack (stage **260**), and configuring a binding strength of the cell separator to the electrode to be higher than a binding strength of the cell separator to the second sacrificial film (stage **270**), e.g., by application of coatings and/or adhesives as disclosed above to any of the cell separator, the second sacrificial film and/or the electrode (stage **252**). For example, the second sacrificial film may be coated, prior to the depositing of the cell separator, with a coating having a lower binding strength to the cell separator than the binding strength of the cell separator to the electrode. Method **200** may further comprise applying at least a pressure on the second stack to carry out lamination (and possibly the delamination) (stage **282**), e.g., by pressing or calendaring, optionally also applying heat to carry out lamination to enhance the binding strength of the cell separator to the electrode. In certain embodiments, method **200** further comprises Pretreating at least one side of the separator (stage **255**). Method **200** may further comprise delaminating the second sacrificial film from the separator while maintaining the attachments of the separator to the electrode and of the electrode to the current collector film (stage **280**).

[00102] Method **200** may optionally further comprise applying at least a pressure on the second stack produced after delamination stage **280** e.g., by pressing or calendaring, optionally also applying heat and configuring the applied pressure (and optionally heat) to enhance the binding strength of the cell separator to the electrode (stage **284**).

[00103] Method **200** may further comprise using the electrode as at least one of an anode and a cathode in a cell (stage **290**), possibly completing at least part of the cell assembly. In certain embodiments, the cell separator may be attached by method **200** to either anode or cathode, and possibly consecutive attaching may be configured to yield a third stack of anode, cell separator and cathode.

[00104] In any of the disclosed embodiments, method **200** may further comprise treating any one of the attached surfaces (**105**) to enhance adhesion and improve the integration of the respective layer and provide more uniform and compact cell structures, resulting in improved electrolyte wetting, cell conductivity (e.g., reduce ESR - equivalent series resistance) and other cell characteristics. For example, electrode surfaces may be pretreated prior to attachments (see e.g., stage **219**) and/or separator surfaces may be pretreated prior to attachments (see e.g., stage **255**). Surface treatment **105**, such as by plasma, may be configured to affect only the surface and not deteriorating the bulk properties of the treated layer, and may additionally improve wetting and ionic conductivity of the treated surface. In case of the separator, surface treatment **105** may be configured to create oxygen termination of surface molecules such as carboxylates, hydroxyls, etc. which may react electrostatically with oxides exposed on the surface of the electrode(s) under pressure, when pressed against each other.

[00105] In certain embodiments, disclosed methods, stacks and electrochemical cells implementing any of surface-treated separators, layer transferring using sacrificial films and/or face-to-face calendaring of the electrode material may be combined and integrated to yield flexible and durable electrode stacks.

[00106] Electrode-preparation methods and systems are provided, in which coated foils, e.g., having dried electrode slurry layers on one or both sides of current collector films, are pressed against each other, with coating layers on the films facing each other and pressing each other. Particularly in lithium ion battery anodes made of metalloid anode material particles, the hardness of the particles may provide more efficient pressing when pressed against each other, than when pressed by an external calendar - leading to thinner, smother and more controllably porous electrodes and higher throughput. Two or more double-sided coated current collector foils may be pressed between external (possibly sacrificial) coated foils, with the coatings on the double-sided foils face each other and the coatings of the respective external foils. Electrodes (e.g., anodes, cathodes) may be prepared from the pressed double-sided coated current collector foils.

[00107] **Figure 8** is a high-level schematic illustration of electrode foils **110** and pressing and/or calendaring unit **170** in electrode production system **150**, according to some embodiments of the invention. Coated current collector foils **101**, composed of a current collector film **104** and coating **102** on at least one side of film **104**, are pressed against each other to yield electrode foils **110** with smooth surfaces **112**. Electrode(s) **95** may then be processed from electrode foils **110**. **Figure 9** is a high-level schematic illustration of prior art electrode production **50**. In the prior art, slurry **62** is applied to a film **60** and pressed by calendar **55** into electrode **65**. In the prior art, at least one of calendars **55** presses the surface of the coating directly. The inventors have found out and show below, that applying pressure by one coating **102** on a facing coating **102** provides smoother resulting coatings **112** (with respect to a surface roughness **67** of prior art electrode foils **65**, see e.g., **Figures 17A**, **17B**), with improved quality and better operation as electrodes in lithium ion batteries. It is noted that spaces between foils and system elements are shown merely for illustration and clarity purposes, as foils pressed against each other contact each other. Any of the embodiments may be implemented by pressing or calendaring unit **170**, possibly as part of various embodiments of electrode production system **150**.

[00108] Electrode production systems **150** comprise two pressure-applying apparatuses **115** (e.g., rotational calendars, linear presses, etc.) facing each other and configured to receive and press, against each other, at least two coated current collector foils **101** having, e.g., dried electrode slurry layers **102** as coatings on current collector films **104**. It is noted that dried electrode slurry coating **102** of current collector films **104** may be configured to optimize mechanical parameters of the process and the resulting characteristics of produced electrode foils **110**.

[00109] In contrast to prior art, pressure-applying apparatuses **115** apply pressure indirectly to coatings **102**, as pressure-applying apparatuses **115** press directly films **104** and not slurry layers **102**. The actual forces applied onto coatings **102**, such as a longitudinal force **125** and a perpendicular force **120** illustrated schematically in **Figure 8**, are applied upon contact of coating layer **102** with the other coating layer **102**, while neither coating layer **102** contacts pressure-applying apparatuses **115**.

[00110] The inventors have found out that avoiding direct contact of pressure-applying apparatuses **115** with coatings **102**, and moreover, the interlayer force application, contribute to forming thinner, smoother and possibly more uniform electrodes foils **110**. The porosity of electrodes foils **110** may be better controlled by the disclosed processes as well. Finally, the throughput of electrode production system **150** of **Figure 8** may be double with respect to prior art electrode production **80** illustrated in **Figure 9**.

[00111] **Figure 10** is a high-level schematic illustration of electrode production system **150**, according to some embodiments of the invention. In certain embodiments, the inventors have found out that mass transfer **122** may occur as result of the disclosed pressing, e.g., due to application of forces **120**, **125** between coating layers **102**. In particular, the inventors have found out that mass transfer **122** may contribute to evening out protrusions **102A** and/or cavities **102B** of coatings **102**, e.g., by mass transfer **122** from the former to the latter as well as by the applications horizontal and vertical evening forces **125**, **120**, respectively. In particular, hard anode material particles as disclosed above may be moved by forces **120**, **125** to yield smoother electrode foils **110**, with evened-out surfaces. Adherence of moved coating mass (e.g., dried electrode slurry mass) during the pressing may be achieved by interaction of material in coating layers **102** such as anode material particles, binder material, polymer material, conductive additives, etc., as well as by the pressing itself through pressure-applying apparatuses **115** and resulting vertical and horizontal forces **120**, **125**.

[00112] **Figures 11A** and **11B** are high-level schematic illustrations of electrode production systems **150**, according to some embodiments of the invention. In certain embodiments, at least two double-sided coated current collector foils **103** (each comprising current collector films **104** and coatings **102** on both sides thereof) may be pressed between external coated foils **101** (each comprising films **104** and coatings **102** on one side thereof). Coatings **102** on double-sided foils **103** face each other and coatings **102** of respective external foils **101**, and are pressed against each other. The pressing by pressure-applying apparatuses **115** forms electrode foils **110A**, **110B** from coated foils **101**, **103**, respectively.

[00113] In certain embodiments, electrode production system **150** may be configured to handle one (**Figure 14**), two (**Figure 17A**), three (**Figure 17B**), or more double-sided coated current collector foils **103** and press foils **110A** therefrom. In certain embodiments, multiple one-sided foils **101** and/or double-sided foils **103** may be pressed simultaneously, with one or more pairs of coating layers **102** pressed against each other therebetween.

[00114] Any of foils **110A**, **110B**, pressed from foils **101**, **103**, may be used to prepare electrodes (e.g., anodes, cathodes) by further processing (e.g., cutting and packaging). It is noted that any one of foils **101**, **103** may be disposable and used as a sacrificial film in the process. In particular, one-sided foils **101** may be used as disposable or reusable sacrificial films.

[00115] **Figures 12-16** are high-level schematic illustrations of electrode production systems **150**, according to some embodiments of the invention. Systems **150** are shown schematically as comprising spools and rollers **106** for handling multiple foils **101**, **103**, **110** to provide industrial production processes using pressure-applying apparatuses **115** to implements disclosed embodiments. **Figures 12-16** illustrate schematically, in a non-limiting manner, various production embodiments. It is noted that spaces between foils and system elements are shown merely for illustration and clarity purposes, as foils pressed against each other contact each other. It is further noted that in any of the disclosed embodiments, heat may be applied during the pressing of coated current collector foils **101**, **103** against each other, by any of several means (e.g., direct heat, convective heat, radiative heat, etc.). Moreover, it is noted that that in any of the disclosed embodiments, process parameters such as thickness of the films and coatings, dimensions and parameters of pressure-applying apparatuses **115**, operation speed and other parameters of spools and rollers **106**, characteristics of heat application etc. may be adjusted according to specified requirements.

[00116] **Figure 12** illustrates schematically calendaring two one-sided foils **101** with their coatings **102** facing each other, similarly to embodiments illustrated schematically in **Figures 8** and **10**. **Figure 13** illustrates schematically calendaring one-sided foil **101** and double-sided foil **103** (having coatings **102** on both sides of film **104**) with coating **102** of foil **101** facing one of coatings **102** of double-sided foil **103** and pressed against it. In certain embodiments, one-sided foil **101** or double-sided foil **103** may be sacrificial foils. In certain embodiments, double-sided foil **103** may be further processed with respect to coating **102** facing pressure-applying apparatuses **115**, possibly using another one-sided foil **101**, or coating **102** facing pressure-applying apparatuses **115** may be left without further pressing. Respective electrode foils **110**, **110A**, **110B** may be formed by the disclosed embodiments of the pressing or calendaring.

[00117] **Figure 14** illustrates schematically calendaring two-sided foil **101** (having coatings **102** on both sides of film **104**) between two one-sided foils **103** (having coatings **102** on the sides of film **104** that face coating **102** of two-sided foil **101**). Respective electrode foils **110A**, **110B** may be formed by the disclosed embodiments of the pressing or calendaring.

[00118] **Figures 15** and **16** illustrate schematically the use of linearly operating presses **115** as pressure-applying apparatuses **115**, applicable in systems **150** in place of, or in addition to, rotationally operating calendars **115** illustrated e.g., in **Figures 12-14**. One-sided foils **103** (having coating **102** on one side of film **104**) and/or two-sided foil **101** (having coatings **102** on both sides of film **104**) may be pressed between external one or two one-sided foils **101** (or possibly one or two two-sided foils **101**, see e.g., **Figure 13**), which may be disposable or reusable as sacrificial layers. For example, **Figure 15** illustrates schematically using one-sided foil **101** as sacrificial layer (bottom layer) when pressing another one-sided foil **101** (top layer), while **Figure 16** illustrates schematically using two one-sided foils **101** as sacrificial layers when pressing one two-sided foil **103**.

[00119] It is noted that in **Figures 8** and **11-16**, spaces between layers **102** that are pressed against each other and spaces between pressure-applying apparatuses **115** and films **104** - are shown only for clarity reasons (cross section shown in exploded view), as clearly the pressing involves contact between the respective structures.

[00120] In certain embodiments, systems **150** may comprise members configured to surface-treat at least one separator film and to attach the surface-treated separator to at least one of the coated foils, which may be coated e.g., with electrode slurry, and attached to the separator(s) at their treated surface(s), as illustrated e.g., in **Figures 1A**, **1B**.

[00121] **Figures 17A** and **18A** illustrate examples of cross-sections of prior art electrode foils **65**, while **Figures 17B** and **18B** illustrate examples of cross-sections of electrode foils **110** prepared according to some embodiments of the invention. The illustrated examples were imaged by scanning electron microscope (SEM).

[00122] As an example for the improved quality of one-sided electrode foils **110**, **Figure 17B** illustrates a cross-section of one-sided electrode foil **110** prepared by pressure-applying apparatuses **115** as explained above, according to some embodiments of the invention, with respect to **Figure 17A** illustrating a cross-section of prior art one-sided electrode foil **65**. Electrode foil **110** is clearly flatter, thinner and has smother surface **112** (with respect to prior art surface **67**) and may have a more uniform internal structure with better controllable porosity than prior art electrode foils **65**.

[00123] As another example for the improved quality of double-sided electrode foils **110**, **Figure 18B** illustrates a cross-section of double-sided electrode foil **110** prepared by pressure-applying apparatuses **115** as explained above, according to some embodiments of the invention, with respect to **Figure 18A** illustrating a cross-section of prior art double-sided electrode foil **65**. Electrode foil **110** is clearly flatter, thinner and has smother surface **112** (with respect to prior art surface **67**) and may have a more uniform internal structure with better controllable porosity than prior art electrode foils **65**.

[00124] **Figures 19A-19C** are examples for disclosed separators **75** and stacks **108** prepared according to disclosed methods **200**, compared to prior art separators and stacks. **Figure 19A** is an image of laminate stack **108**, according to some embodiments of the invention. Laminate stack **108** is thin and uniform, having good and stable attachment of separator **75** and electrodes **95**. **Figure 19B** is a comparison of laminated stack **108** with prior art stack **68** in which cathode foil **68** is not attached well to untreated separator **61**. **Figure 19C** demonstrates the better wettability of surface-treated separator **75** by the electrolyte, measured by the sessile drop method, according to some embodiments of the invention, with respect to untreated separator **61**. The better wettability indicates the surface activation of separator **75** which enables it to attach to electrodes **95** as disclosed below, as well as improving its wettability towards the electrolyte.

[00125] In the non-limiting illustrated examples of **Figures 19A-19C**, a polyethylene membrane film having a monolayer architecture with a thickness of 12 microns and about 41% porosity was used as the separator, the anode was based on Ge anode material, coated on a Cu film as current collector to form a layer ca. 20μm thick. The cathode was based on NCA coated on Al film and having a thickness of about 50μm. The separator membrane and electrodes were treated in an Ar or dry air microwave plasma applicator under different conditions, e.g., 18W applied for 1-3 minutes. Right after plasma treatment, the separator and electrodes were laminated under dry air environment (dew point -40°C). Cold lamination was performed using a two-roll calendar tool at temperatures below 55°C, and resulted in a strong bond between the electrodes and separator, as illustrated in **Figure 19A** while untreated separator films, under the same stacking and process conditions, did not yield stable attachment to the electrodes (**Figure 19B**). No changes in the stacking (bonding) of the laminated electrodes and separator after plasma treatment were observed after ten days stored under air environment. The laminated and non-laminated electrodes and separators were closed to soft pack pouch cells with EMC-based electrolyte. The laminated cells showed increased cycle life under high charging rates, as illustrated below (see **Figures 22A-22C**).

[00126] It is noted that the plasma treatment bay be carried out under different conditions, which may be adjusted and optimized with respect to each other and according to the materials used in the batteries, e.g., the power and duration of surface treatment **105** may vary in the ranges 10-600W power for 1000-10seconds, respectively (the higher the applied power is, the shorter is the duration of the surface treatment).

[00127] **Figure 19D** is a SEM image of prior art double sided electrode (anode) produced not using the disclosed lamination process, and exhibiting rough and non-uniform anode surfaces.

[00128] **Figures 20A** and **20B** are SEM images of prepared laminated separators **75** and electrodes **95**, according to some embodiments of the invention. **Figure 20A** illustrates laminated cathode **95B**, separator **75** and anode **95A**, and **Figure 20B** illustrates pairs of laminated anode **95A** and separator **75**, and cathode **95B** separator **75** – all of which indicating the production quality of laminated stacks **108**. As illustrated in the SEM images, electrodes **95** are uniform and thin, and are uniformly and securely attached to separator **75**.

[00129] **Figure 21** provides SEM images of the surfaces of anode **95A**, cathode **95B** and separator **75**, respectively, before and after surface treatment **105** by plasma, in a non-limiting example, according to some embodiments of the invention. No surface damage or other surface morphology changes were observed on the separator and electrodes after the plasma treatment. Energydispersive X-ray spectroscopy showed oxygen termination on the surface such as carboxylates, hydroxyls, etc. as disclosed above, serving as binding sites **105A** on separator **75** and/or surface elements **105B** on electrodes **95** during the lamination process, to yield improved laminated stacks **108**.

[00130] **Figures 22A-22C** illustrate prior art cell assembly with its cycling characteristics and cycling characteristics of laminated stacks **108** illustrated in **Figure 19A**, in a non-limiting example, according to some embodiments of the invention. Laminated stacks **108** were prepared by laminating an anode, a separator, and a cathode using the calendaring procedure after plasma surface pretreatment and assembling the stack into a soft package pouch cell with EMC-based electrolyte. The prior art stack illustrated in **Figure 22A** was prepared without plasma pretreatment, attaching the anode, separator, and cathode without plasma pretreatment, by sticking the electrodes and separator together with a glue strip during cell assembly. An additional prior art stack assembly was carried out without plasma pretreatment and without additional attaching of the electrodes and separator, which resulted in cells with very high internal resistance onto which fast charging (at 8C) was not applicable at all. In the prior art cells, the same EMC-based electrolyte was used. All cells were run at a standard procedure of formation and cycled at 8C/1C charging/discharging rates. **Figures 22B** and **22C** illustrate the cycling characteristics of the prior art stack of **Figure 22A** and of laminated stack **108** of **Figure 19A**, respectively. The cycling characteristics comprise the charged and discharged capacities, Columbic efficiency (cycling efficiency) and capacity retention form the initial value. Similar behavior of two cells is observed, clearly indicating the efficiency and compatibility of surface treatment and cold lamination described above, and provide improved cycling efficiency and capacity retention with respect to the prior art cells.

[00131] Disclosed electrode foils **110** may be used as anodes in energy storage devices, such as lithium ion batteries. The electrode slurry, and consequently coatings **102** and electrode foils **110**, may comprise anode material in form of anode material particles (e.g., having a diameter of 100-500nm), which may comprise e.g., particles of metalloids such as silicon, germanium and/or tin, and/or possibly particles of aluminum, lead and/or zinc, and may further include various particle surface elements (e.g., having a diameter of 10-50nm or less) such nanoparticles (e.g., B_4C, WC, VC, TiN), borate and/or phosphate salt(s) and/or nanocrystals and possibly polymer coatings (e.g., conductive polymers, lithium polymers). The electrode slurry may be prepared by ball milling processes and may further comprise additive(s) such as binder(s), plasticizer(s) and/or conductive filler(s). Drying of slurry spread on film **104** to form dried slurry layer(s) **102** may be carried out may be carried out with or without further intervention, the former possibly involving controlling environmental conditions (e.g., temperature, humidity), applying direct heat or air flow and/or controlling evaporation parameters.

[00132] Without being bound by theory, the inventors suggest that the thinner and more uniform electrodes **110** may be a result of forces **120**, **125** acting between the anode material particles in each electrode **110** and between electrodes **110**, respectively, instead of between electrode **65** and calendar **55** as in the prior art. For example, the direct application of forces among anode material particles in dried slurry layers **102**, being pressed against each other, may yield a smoother surface of electrodes **110** by evening out the surface more efficiently than by pressing against the large external calendar **55** of the prior art (e.g., larger, or more effectively applied forces **125**). Moreover, as in some embodiments, the anode material particles have a higher strength than the material of prior art calendar **55** (e.g., Si/Ge anode material particles with B_4C/WC nanoparticles or coatings versus aluminum of prior art calendar **55**) larger forces may be applied in the disclosed invention than in the prior art, possibly leading to more efficient smoothing (e.g., larger forces **120**). In certain embodiments, the similar composition of dried slurry layers **102** being pressed against each other - may yield a smoother and/or more uniform product electrode **110** than resulting from prior art asymmetry between pressed film **60** and pressing calendar **55**, which are typically made of different materials and have different structural parameters and characteristics.

[00133] Advantageously, disclosed method **200** and systems **150**, in any of their embodiments and/or combinations, may provide improved electrodes, which are more uniform (in bulk and/or on their surface) and operate better in lithium ion cells. For example, electrode foils **110** may have fewer and/or less sharp protrusions **102A**, reducing the probability for charge accumulation at the protrusions), have a more uniform thickness, reducing the expansion of the electrode during the charging cycles. Moreover, the better adhesion and uniformity achieved through disclosed methods **200** and systems **150** also reduce the resistance of the electrode and therefore improve the cell's performance.

[00134] In the above description, an embodiment is an example or implementation of the invention. The various appearances of "one embodiment”, "an embodiment", "certain embodiments" or "some embodiments" do not necessarily all refer to the same embodiments. Although various features of the invention may be described in the context of a single embodiment, the features may also be provided separately or in any suitable combination. Conversely, although the invention may be described herein in the context of separate embodiments for clarity, the invention may also be implemented in a single embodiment. Certain embodiments of the invention may include features from different embodiments disclosed above, and certain embodiments may incorporate elements from other embodiments disclosed above. The disclosure of elements of the invention in the context of a specific embodiment is not to be taken as limiting their use in the specific embodiment alone. Furthermore, it is to be understood that the invention can be carried out or practiced in various ways and that the invention can be implemented in certain embodiments other than the ones outlined in the description above.

[00135] The invention is not limited to those diagrams or to the corresponding descriptions. For example, flow need not move through each illustrated box or state, or in exactly the same order as illustrated and described. Meanings of technical and scientific terms used herein are to be commonly understood as by one of ordinary skill in the art to which the invention belongs, unless otherwise defined. While the invention has been described with respect to a limited number of embodiments, these should not be construed as limitations on the scope of the invention, but rather as exemplifications of some of the preferred embodiments. Other possible variations, modifications, and applications are also within the scope of the invention. Accordingly, the scope of the invention should not be limited by what has thus far been described, but by the appended claims and their legal equivalents.

CLAIMS

1. A method comprising:

   surface treating at least one cell separator prior to attachment to at least one electrode, wherein the surface treating is configured to form binding sites on the at least one cell separator, and

   attaching the at least one cell separator to the at least one electrode by cold press lamination, wherein the created binding sites are configured to stabilize the cold press lamination electrostatically.
2. The method of claim 1, further comprising applying the surface treatment to both sides of the at least one cell separator and wherein the at least one electrode comprises, for each of the at least one cell separator, an anode attached to one side of the separator and a cathode attached to another side of the separator.
3. The method of claim 2, wherein both anode and cathode are attached to the separator simultaneously.
4. The method of claim 2, further comprising assembling a cell stack by performing the attachment to a plurality of cell separator and a corresponding plurality of alternating anodes and cathodes.
5. A flexible battery comprising the assembled cell stack prepared by the method of any one of claims 1-4.
6. The method of claim 1, wherein the cold press lamination is carried out below 60°C and/or below 40 and/or at room temperatures.
7. The method of claim 1, wherein the surface treatment is carried out by any of plasma treatment, corona treatment, ultraviolet radiation.
8. The method of claim 1, wherein the surface treatment is carried out by depositing an ionic-conductive surface layer to form the binding sites.
9. The method of claim 1, wherein the at least one cell separator is polymeric and the surface treatment comprises depositing a ceramic surface layer onto the polymeric at least one cell separator.
10. The method of any one of claims 1-9, wherein the at least one electrode comprises attached corresponding at least one current collector film.
11. The method of claim 10, wherein the at least one electrode is attached to the corresponding at least one current collector film by a conductive adhesive.

12. The method of claim 1, wherein the attaching is carried out using a sacrificial film onto which at least one of: at least one cell separator and the at least one electrode, are deposited as corresponding slurry.
13. The method of any one of claims 1-12, further comprising pressing the at least one electrode face-to-face against another electrode prior to the attaching of the at least one cell separator.
14. The method of any one of claims 1-13, wherein the attaching is carried out by at least one of: single sheet stacking, winding, Z-folding with single electrodes and Z-folding with electrode rolls.
15. The method of claim any one of claims 1-14, further comprising:

    prior to the surface treatment, depositing a cell separator slurry on a sacrificial film to form a cell separator thereupon, and

    following the surface treatment:

      attaching the formed cell separator onto the at least one electrode attached to at least one corresponding current collector film, to yield a stack, wherein a binding strength of the cell separator to the electrode is higher than a binding strength of the cell separator to the sacrificial film, and

      delaminating the sacrificial film from the separator while maintaining the attachments of the separator to the electrode and of the electrode to the current collector film.
16. The method of claim 15, further comprising preparing the at least one electrode attached to the at least one corresponding current collector film by:

    depositing an electrode slurry on a sacrificial film to form the at least one electrode thereupon, wherein the electrode slurry comprises a first solvent,

    attaching a current collector film, which is produced using a second solvent, onto the formed electrode, to yield a stack, wherein a binding strength of the electrode to the current collector film is higher than a binding strength of the electrode to the sacrificial film, and

    delaminating the sacrificial film from the electrode while maintaining the attachment of the electrode to the current collector film.
17. The method of claim 16, further comprising:

    pressing at least two double-sided coated current collector foils between external coated foils, wherein the coatings on the double-sided foils comprise the electrode slurry and face each other and the coatings of the respective external foils, and are pressed against each other, and preparing the electrodes from at least one of the pressed double-sided coated current collector foils.

18. The method of claim 16, further comprising preparing the at least one electrode attached to the at least one corresponding current collector film by:

    pressing at least two double-sided coated current collector foils between external coated foils, wherein the coatings on the double-sided foils comprise electrode slurry and face each other and the coatings of the respective external foils, and are pressed against each other, and

    preparing electrodes from at least one of the pressed double-sided coated current collector foils.

19. A cell stack assembly system comprising:

    a surface treatment module configured to treat both surfaces of each of a plurality of cell separators, to form binding sites thereupon,

    a stacking module configured to stack a plurality of alternating anodes and cathodes between the cell separators, and

    a cold-press lamination module configured to cold-press the stack, wherein the formed binding sites are configured to stabilize the cold-pressed stack electrostatically.

20. The cell stack assembly system of claim 19, further comprising at least one of:

    a layer transfer module configured to prepare the at least one electrode attached to at least one corresponding current collector film by depositing an electrode slurry on a sacrificial film to form the at least one electrode thereupon, wherein the electrode slurry comprises a first solvent; attaching a current collector film, which is produced using a second solvent, onto the formed electrode, wherein a binding strength of the electrode to the current collector film is higher than a binding strength of the electrode to the sacrificial film; and delaminating the sacrificial film from the electrode while maintaining the attachment of the electrode to the current collector film, and

    a calendaring unit comprising two pressure-applying apparatuses facing each other and configured to receive and press, against each other, at least two double-sided coated current collector foils between external coated foils, wherein the coatings on the double-sided foils face each other and the coatings of the respective external foils, and are pressed against each other, and wherein the two pressure-applying apparatuses are configured to apply pressure on the external coated foils.

21. A cell stack for lithium ion batteries, the cell stack comprising a plurality of anodes and cathodes, separated by a plurality of cell separators,
    wherein at least one of the anodes, the cathodes and the cell separators are surface treated to form binding sites upon surfaces thereof, and
    wherein the anodes, the cathodes and the cell separators are attached by cold press lamination, electrostatically stabilized by the created binding sites.
22. A method comprising:

    surface treating, prior to stack lamination, at least one cell separator and/or at least one electrode, wherein the surface treating is configured to form binding sites on the at least one cell separator and/or at least one electrode, respectively, and

    laminating, by cold press lamination, a stack of multiple alternating separators and electrodes, comprising the at least one separator and the at least one electrode, at least one of which being surface treated by said surface treating,

    wherein the created binding sites are configured to stabilize the cold press lamination electrostatically.
23. The method of claim 22, further comprising attaching the alternating separators and electrodes by at least one of: single sheet stacking, winding, Z-folding with single electrodes and Z-folding with electrode rolls.
24. The method of claim 22, wherein the surface treatment is carried out by any of plasma treatment, corona treatment, ultraviolet radiation.
25. The method of claim 22, wherein the stack of multiple alternating separators and electrodes comprises at least one of: a single separator and a single electrode, a single separator and two electrodes on either side thereof, a single electrode and two separators on either side thereof, an alternating plurality of separators and plurality of electrodes.
26. The method of claim 22, wherein the stack of multiple alternating separators and electrodes comprises a single separator foil and two electrodes foils which are laminated to on either side of the separator foil by a roll to roll process.
27. A method comprising:

    depositing an electrode slurry on a sacrificial film to form an electrode thereupon, wherein the electrode slurry comprises a first solvent, attaching a current collector film, which is produced using a second solvent, onto the formed electrode, to yield a stack, wherein a binding strength of the electrode to the current collector film is higher than a binding strength of the electrode to the sacrificial film, and

delaminating the sacrificial film from the electrode while maintaining the attachment of the electrode to the current collector film.

28. The method of claim 27, wherein the attaching is carried out by lamination.
29. The method of claim 28, further comprising applying a pressure on the stack to carry out the lamination.
30. The method of claim 29, wherein the pressure application is carried out by pressing or calendaring.
31. The method of claim 29, further comprising applying heat to carry out the lamination.
32. The method of claim 29, further comprising configuring the applied pressure to enhance the binding strength of the electrode to the current collector film.
33. The method of any one of claims 27-32, further comprising coating the current collector film with a conductive adhesive prior to the attaching.
34. The method of any one of claims 27-32, further comprising coating the sacrificial film, prior to the depositing, with a coating having a lower binding strength to the electrode than the binding strength of the electrode to the current collector film.
35. The method of claim 34, wherein the attaching is carried out by lamination and the method further comprises applying at least a pressure on the stack to carry out the lamination, wherein the coating is configured to have the lower binding strength at least upon the pressure application.
36. The method of any one of claims 27-35, further comprising coating the electrode with a conductive adhesive prior to the attaching.
37. The method of any one of claims 27-36, further comprising coating the current collector film with a carbon coating that is attached to the electrode.
38. The method of any one of claims 27-37, further comprising configuring the current collector film to have a patterned, mesh-like and/or foam-like structure.
39. The method of any one of claims 27-38, further comprising wetting at least one of the electrode and the current collector film to enhance adhesiveness therebetween.
40. The method of claim any one of claims 27-39, further comprising, consecutively,

depositing a cell separator slurry on a second sacrificial film to form a cell separator thereupon,

attaching the electrode, which is attached to the current collector film, onto the formed cell separator, to yield a second stack, wherein a binding strength of the cell separator to the electrode is higher than a binding strength of the cell separator to the second sacrificial film, and

delaminating the second sacrificial film from the separator while maintaining the attachments of the separator to the electrode and of the electrode to the current collector film.

41. The method of claim 40, wherein the attaching of the electrode is carried out by lamination.
42. The method of claim 41, further comprising applying at least a pressure on the second stack to carry out the lamination.
43. The method of claim 40, further comprising configuring the applied pressure to enhance the binding strength of the cell separator to the electrode.
44. The method of claim 40, further comprising coating the second sacrificial film, prior to the depositing of the cell separator, with a coating having a lower binding strength to the cell separator than the binding strength of the cell separator to the electrode.
45. The method of any one of claims 27-45, further comprising using the electrode as at least one of an anode and a cathode in a cell.
46. A flexible battery prepared by the method of any one of claims 27-45.
47. An electrode-preparation method comprising:

    pressing at least two double-sided coated current collector foils between external coated foils, wherein the coatings on the double-sided foils face each other and the coatings of the respective external foils, and are pressed against each other, and

    preparing electrodes from at least one of the pressed double-sided coated current collector foils.

48. The electrode-preparation method of claim 47, wherein the pressing is carried out rotationally by calendaring.
49. The electrode-preparation method of claim 47, wherein the pressing is carried out linearly and the external coated foils are disposable.
50. The electrode-preparation method of any one of claims 47-49, further comprising applying heat to at least one of the foils during the pressing.

51. The electrode-preparation method of any one of claims 47-50, wherein the pressing is configured to cause mass transfer between protrusions and cavities of the coatings on the respective facing foils, to even out surfaces thereof.
52. The electrode-preparation method of any one of claims 47-51, wherein the coatings comprise dried electrode slurry.
53. An anode prepared by the electrode-preparation method of any one of claims 47-52.
54. A cathode prepared by the electrode-preparation method of any one of claims 47-52.
55. A lithium ion cell comprising at least one of the anode of claim 53 and the cathode of claim 54.
56. An electrode production system comprising two pressure-applying apparatuses facing each other and configured to receive and press, against each other, at least two double-sided coated current collector foils between external coated foils, wherein the coatings on the double-sided foils face each other and the coatings of the respective external foils, and are pressed against each other, and wherein the two pressure-applying apparatuses are configured to apply pressure on the external coated foils.
57. The electrode production system of claim 56, wherein the pressure-applying apparatuses are calendars.
58. The electrode production system of claim 56, wherein the pressure-applying apparatuses are linear presses and the external coated foils are disposable.
59. The electrode production system of claim 56, further configured to cause mass transfer between protrusions and cavities of the coatings on the respective facing foils, to even out surfaces thereof.

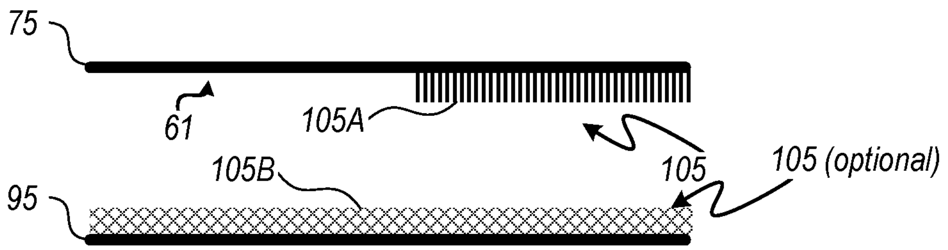


Figure 1A

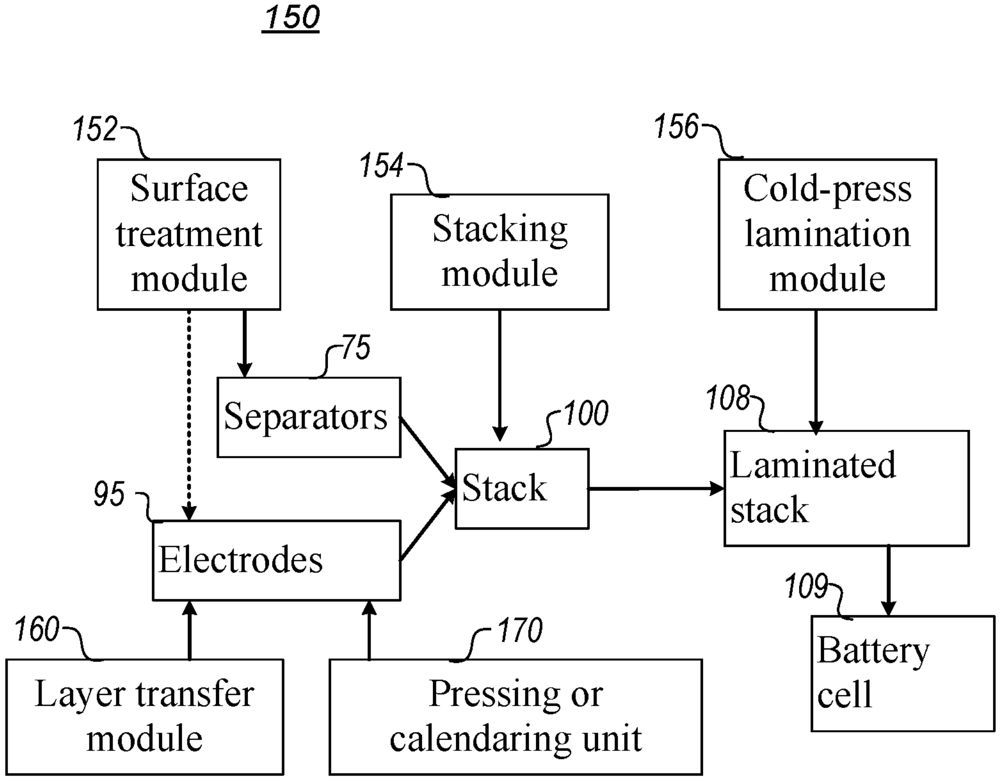


Figure 1B

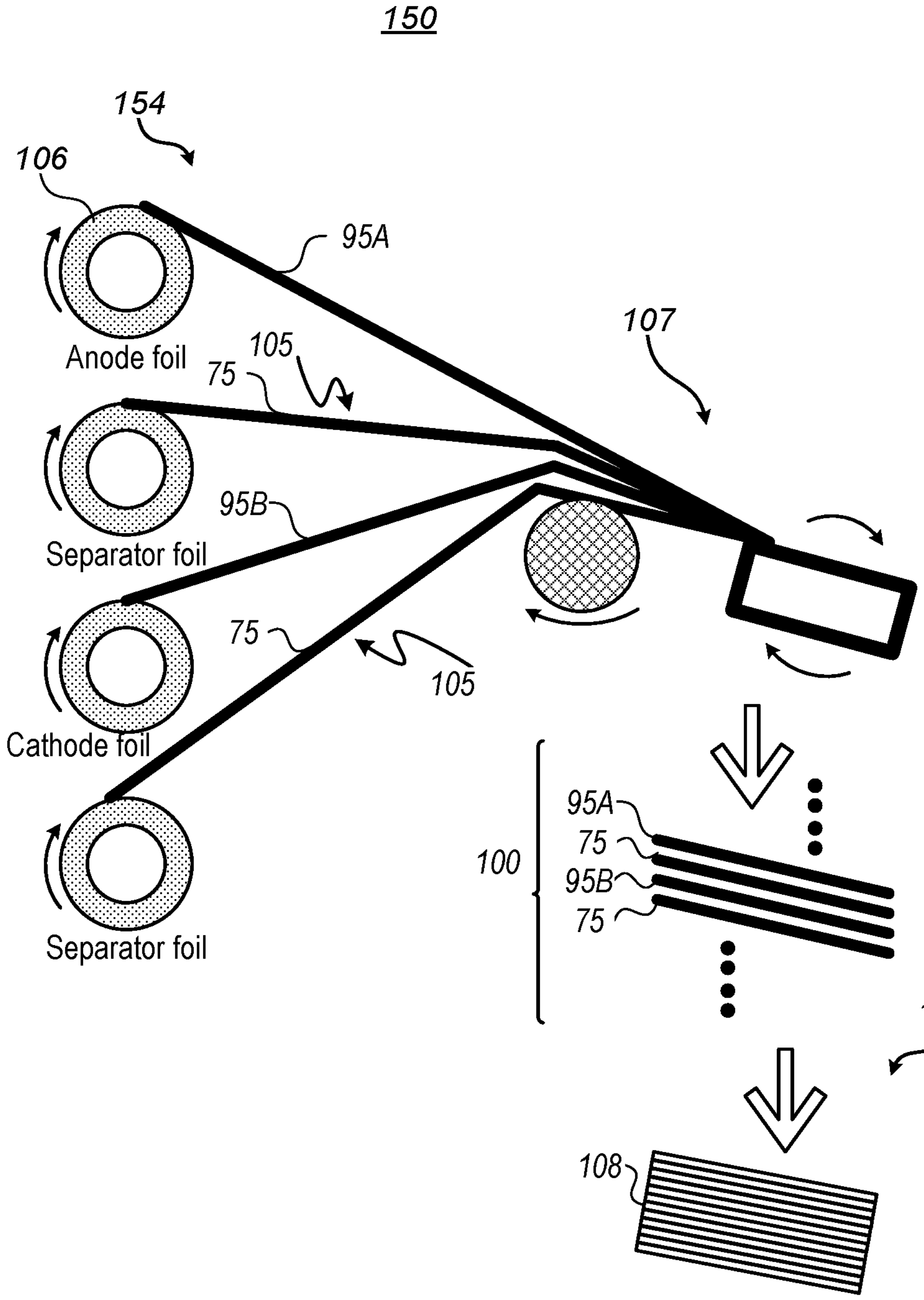

150
154
106
95A
Anode foil
105
75
107
Separator foil
95B
Cathode foil
75
105
Separator foil
95A
75
100
95B
75
156
108

Figure 1C

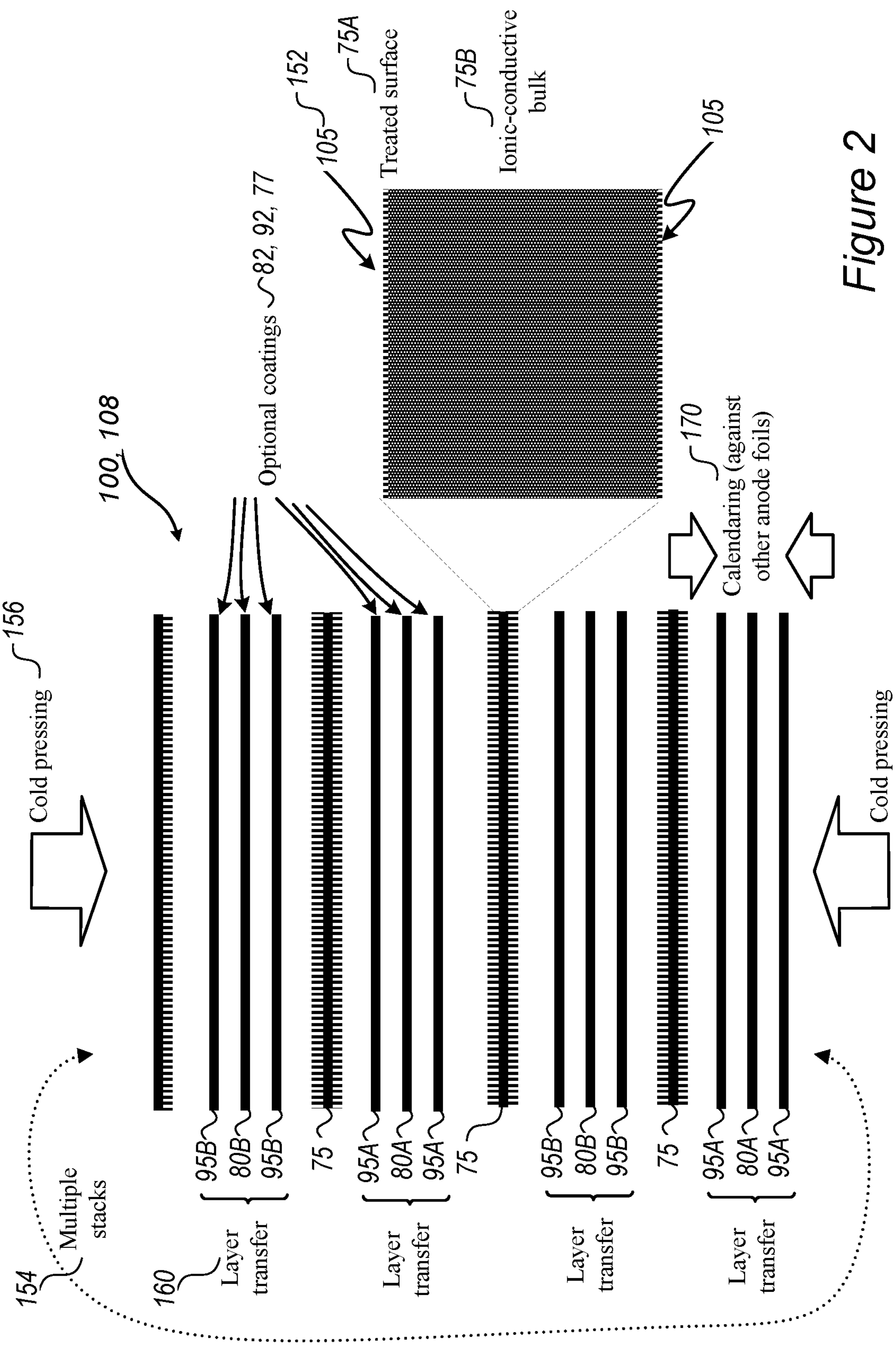

Cold pressing
156
100, 108
Optional coatings
82, 92, 77
105
152
75A
Treated surface
75B
Ionic-conductive bulk
105
170
Calendaring (against other anode foils)
Cold pressing
154
Multiple stacks
160
Layer transfer
95B
80B
95B
75
Layer transfer
95A
80A
95A
75
Layer transfer
95B
80B
95B
75
Layer transfer
95A
80A
95A

Figure 2

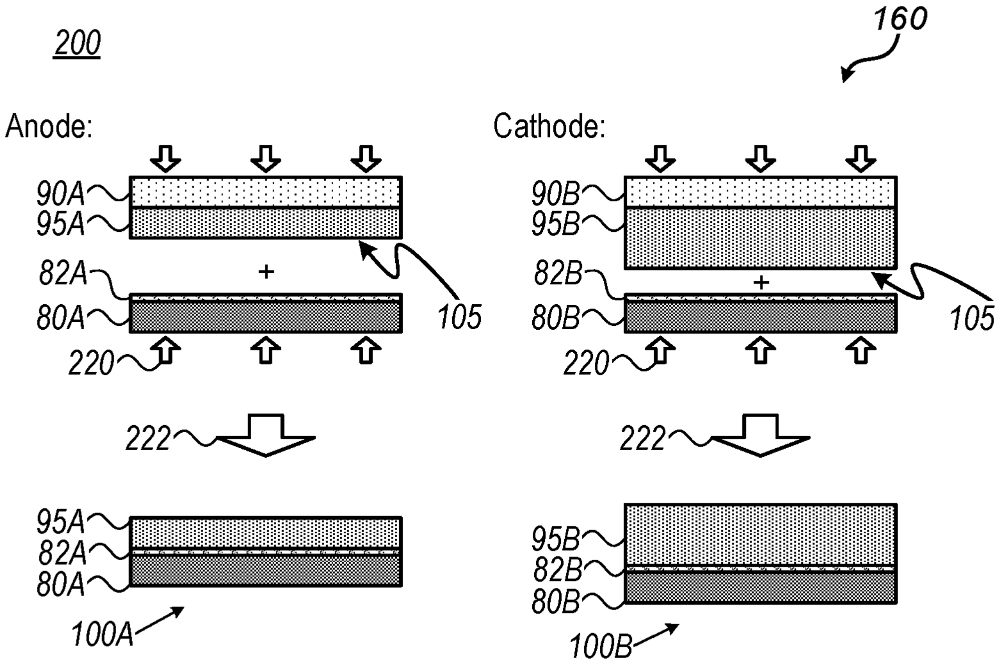


Figure 3A

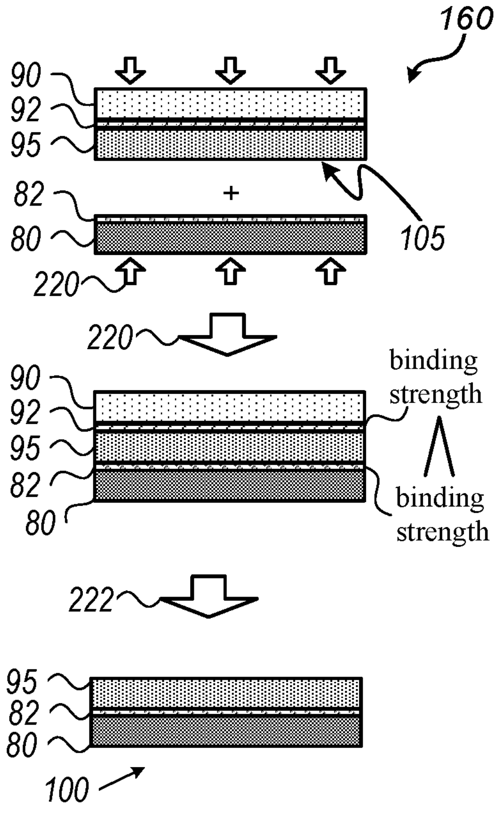


Figure 3B

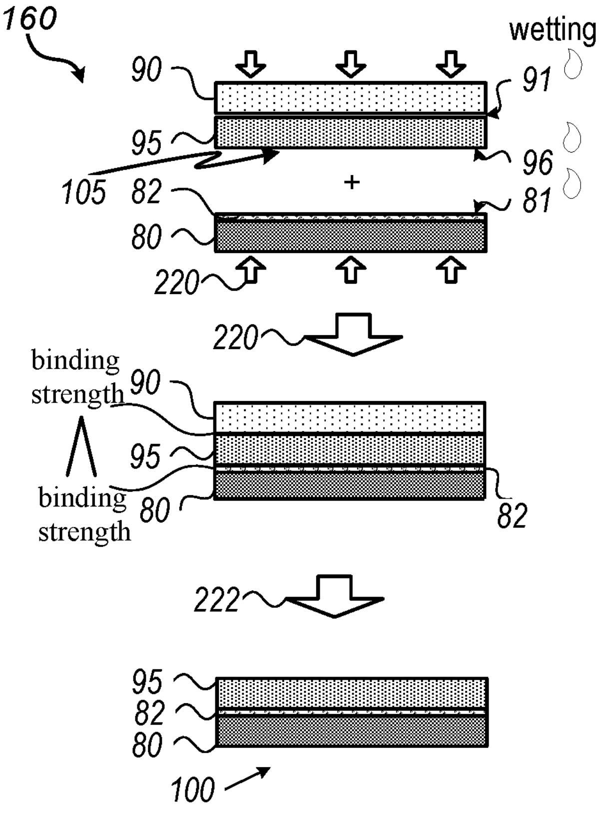


Figure 3C

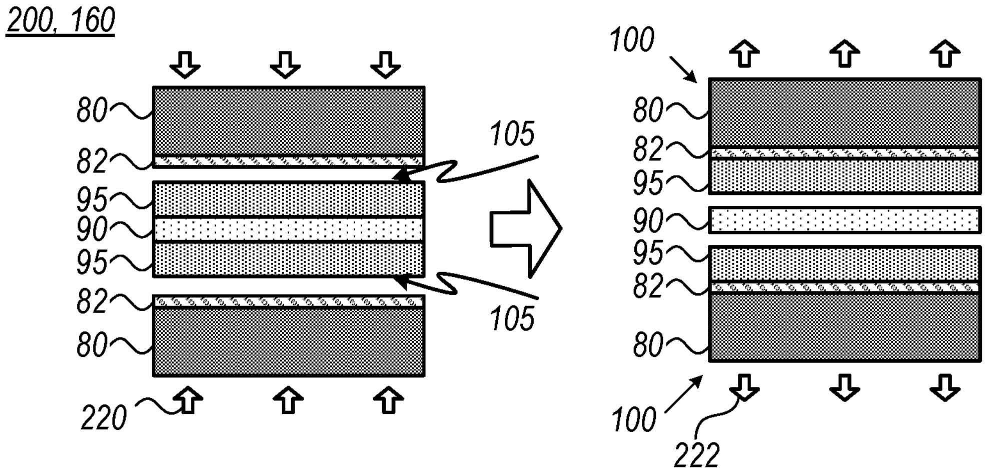


Figure 4A

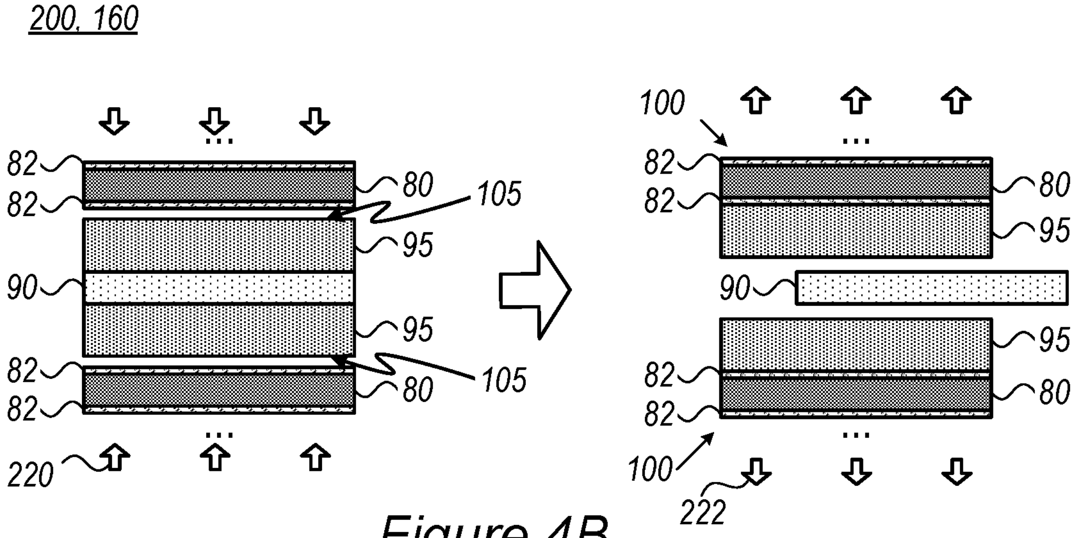


Figure 4B

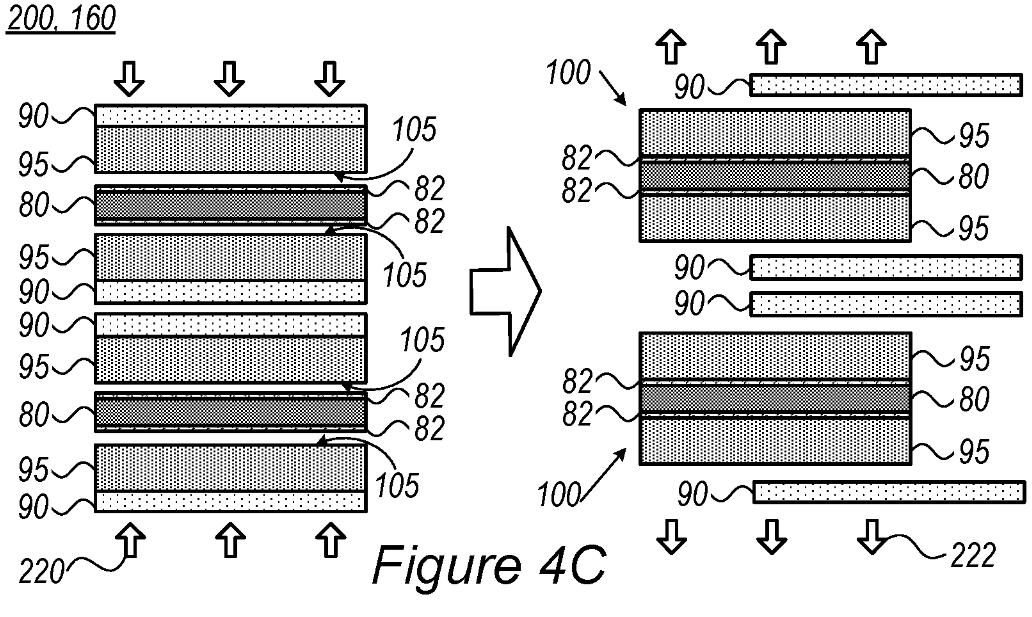


Figure 4C

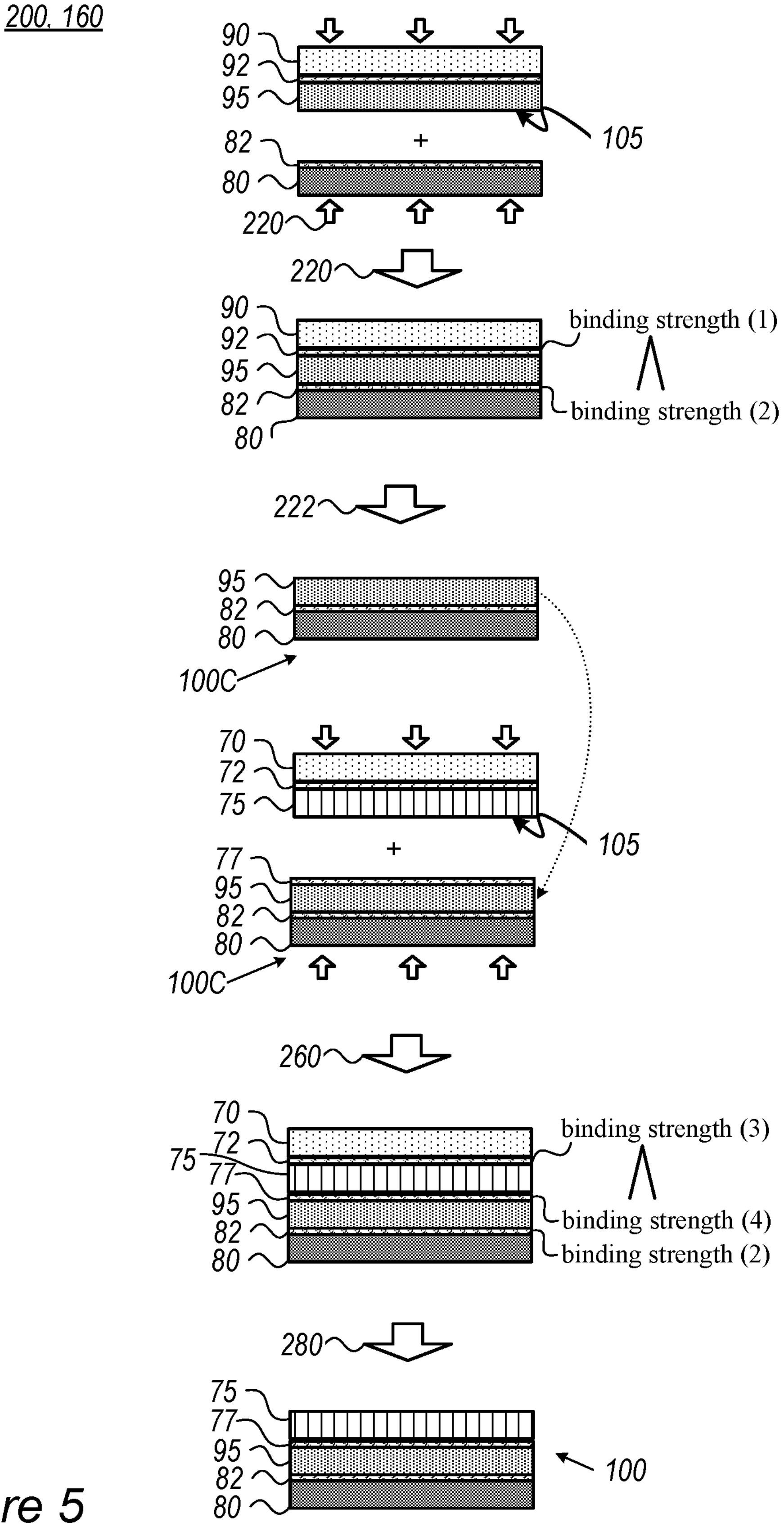

200, 160
90
92
95
105
82
+
80
220
220
90
92
95
82
80
binding strength (1)
binding strength (2)
222
95
82
80
100C
70
72
75
105
+
77
95
82
80
100C
260
70
72
75
77
95
82
80
binding strength (3)
binding strength (4)
binding strength (2)
280
75
77
95
82
80
100

Figure 5

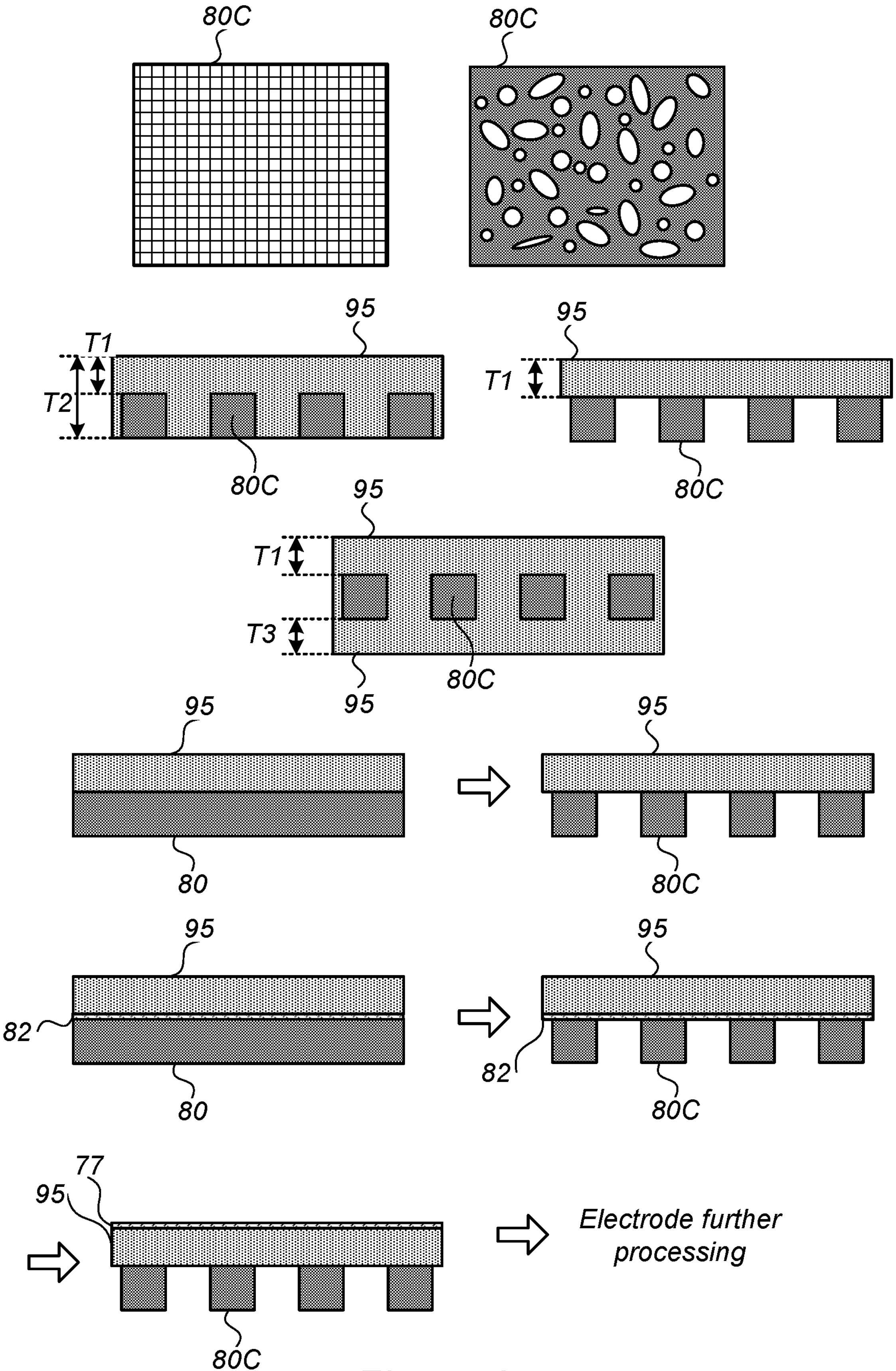

80C
80C
95
T1
T2
80C
95
T1
80C
95
T1
T3
80C
95
95
80
95
80C
95
82
80
95
82
80C
77
95
80C
Electrode further processing

Figure 6

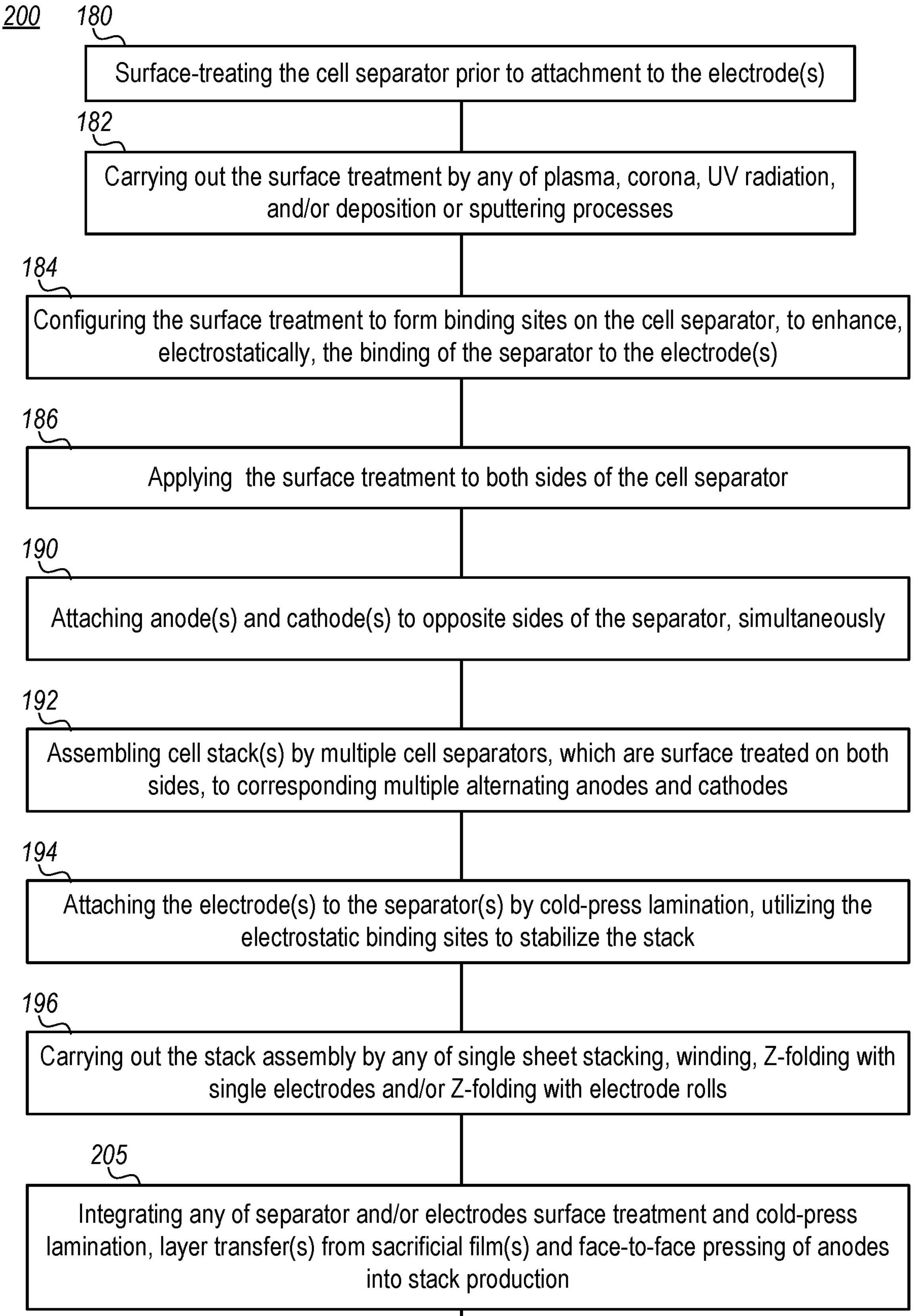

200
180
Surface-treating the cell separator prior to attachment to the electrode(s)
182
Carrying out the surface treatment by any of plasma, corona, UV radiation, and/or deposition or sputtering processes
184
Configuring the surface treatment to form binding sites on the cell separator, to enhance, electrostatically, the binding of the separator to the electrode(s)
186
Applying the surface treatment to both sides of the cell separator
190
Attaching anode(s) and cathode(s) to opposite sides of the separator, simultaneously
192
Assembling cell stack(s) by multiple cell separators, which are surface treated on both sides, to corresponding multiple alternating anodes and cathodes
194
Attaching the electrode(s) to the separator(s) by cold-press lamination, utilizing the electrostatic binding sites to stabilize the stack
196
Carrying out the stack assembly by any of single sheet stacking, winding, Z-folding with single electrodes and/or Z-folding with electrode rolls
205
Integrating any of separator and/or electrodes surface treatment and cold-press lamination, layer transfer(s) from sacrificial film(s) and face-to-face pressing of anodes into stack production

Figure 7

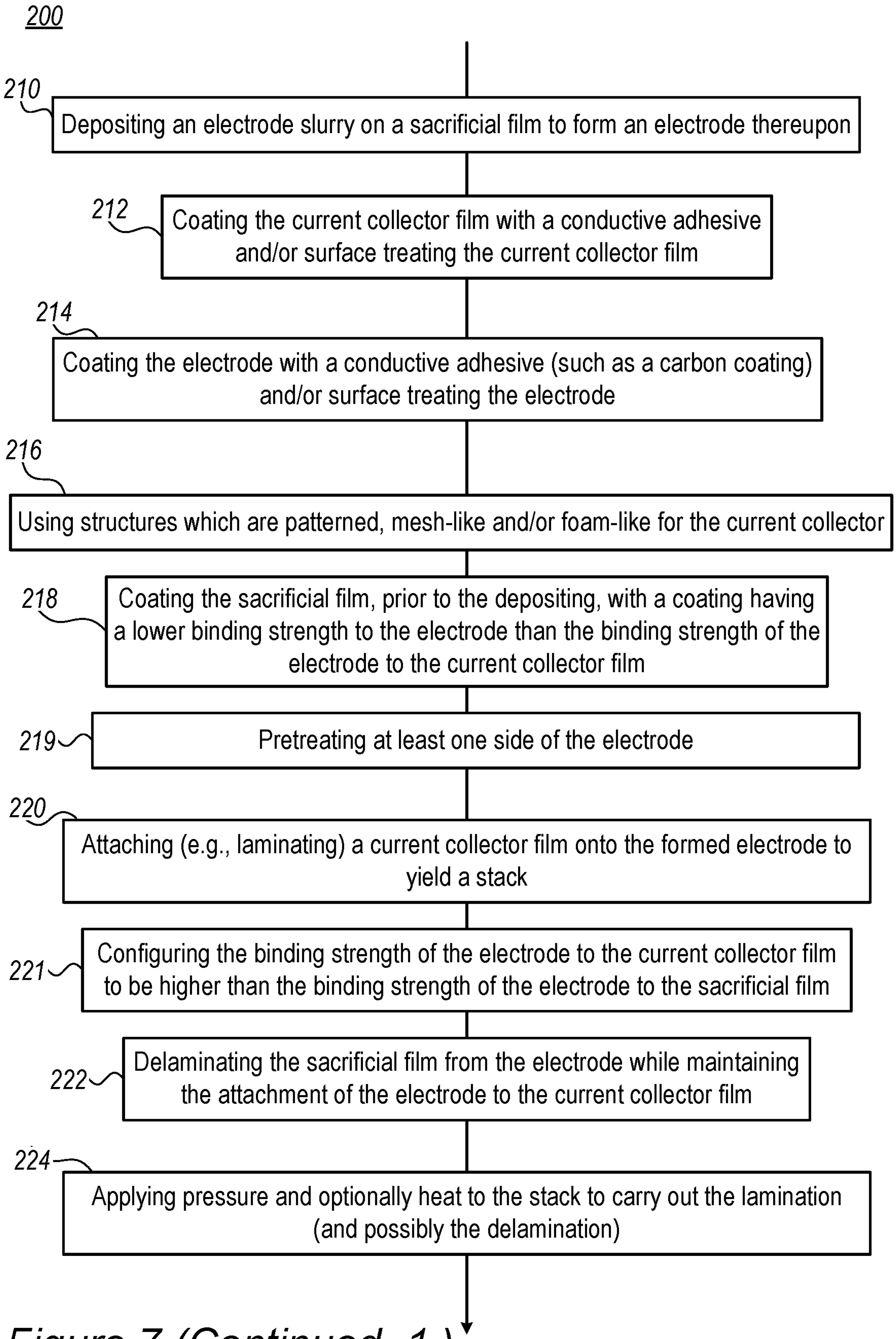


Figure 7 (Continued, 1.)

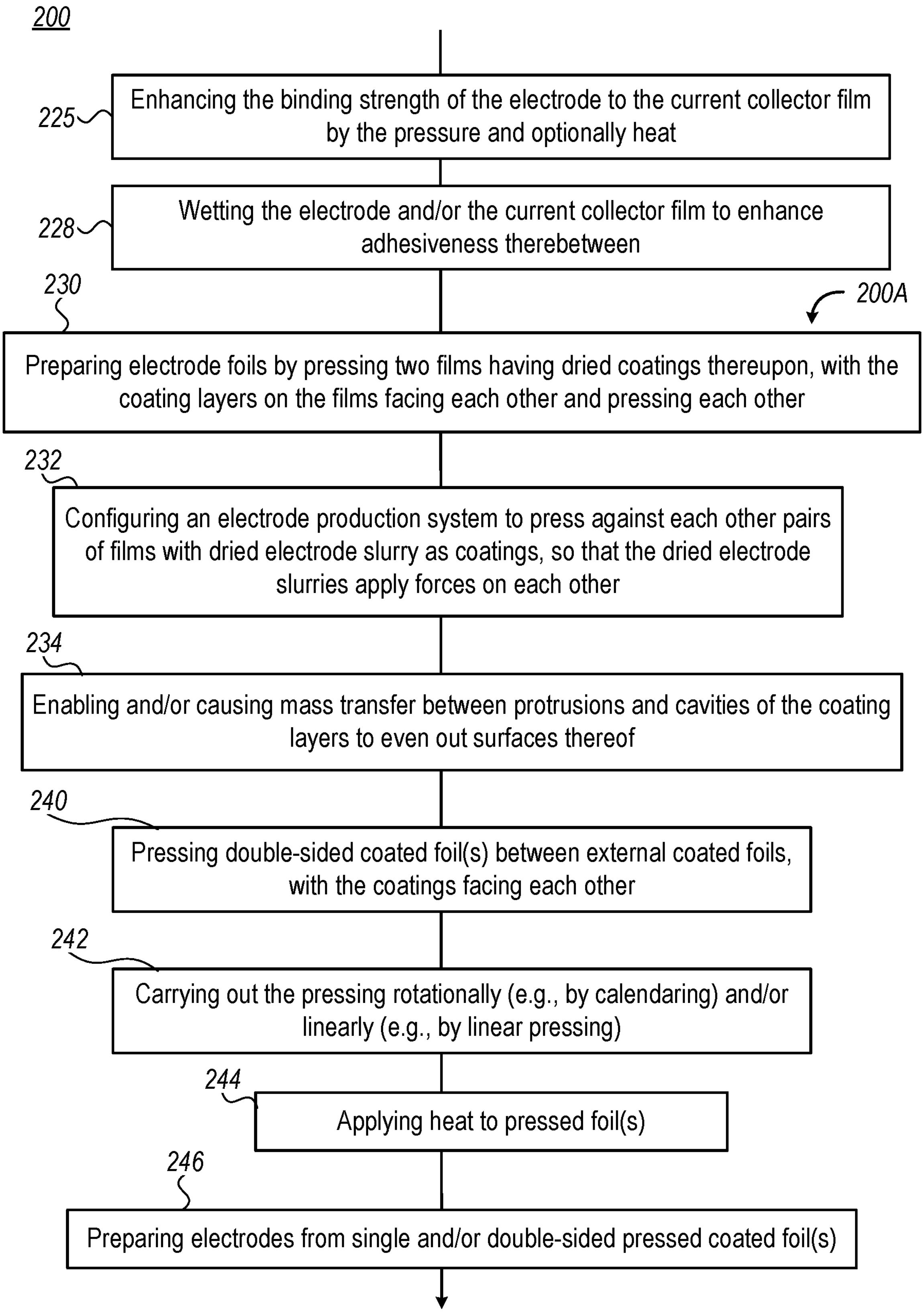


Figure 7 (Continued, 2.)

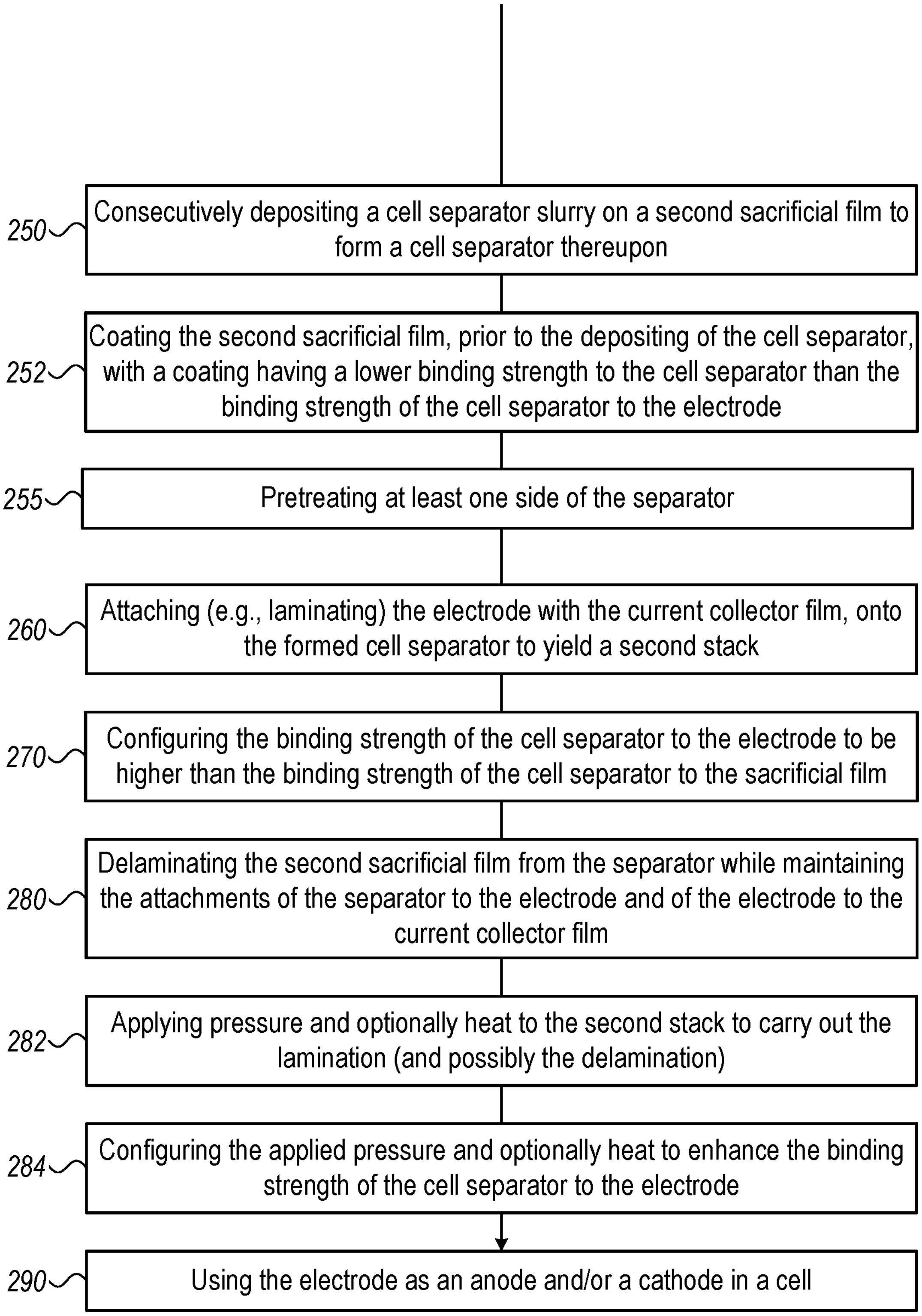


Figure 7 (Continued, 3.)

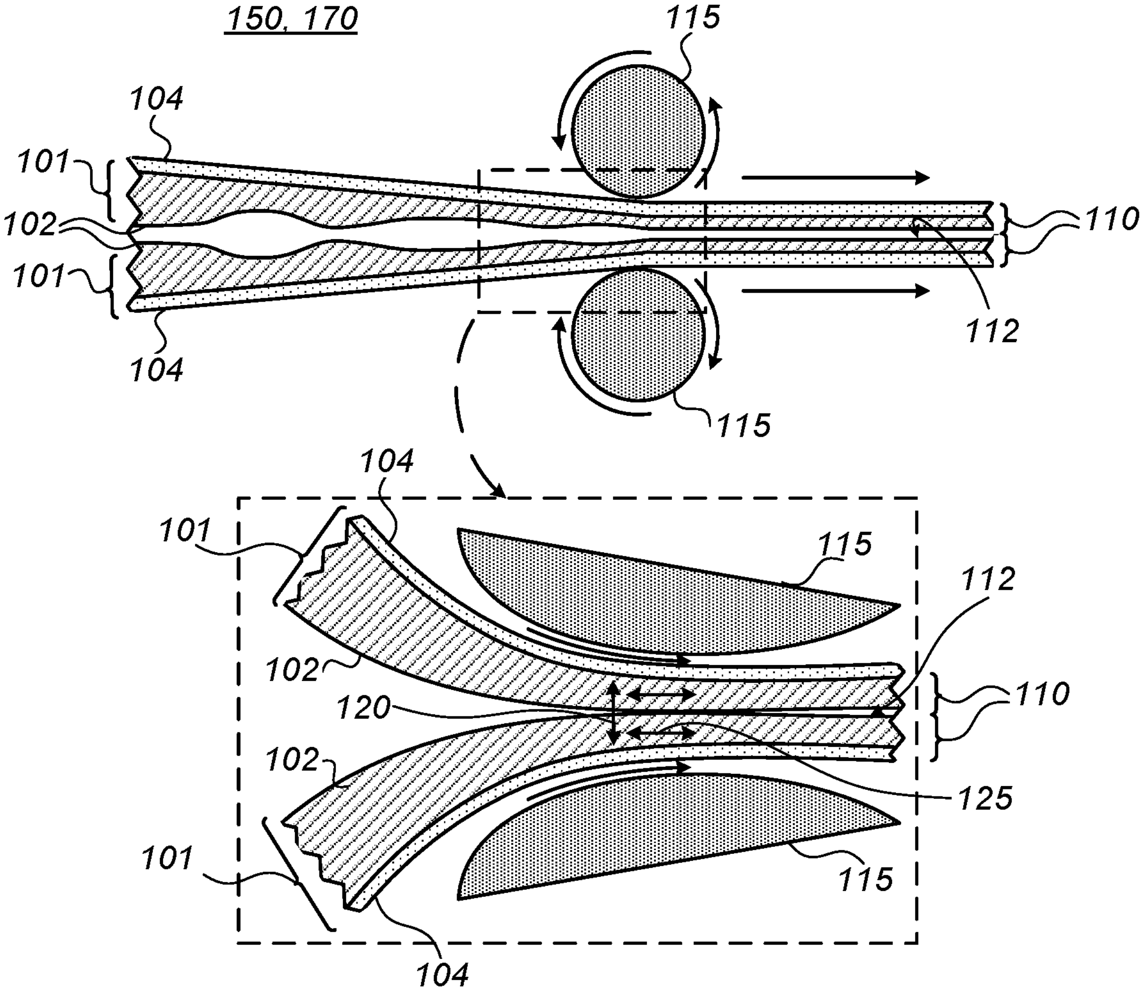


Figure 8

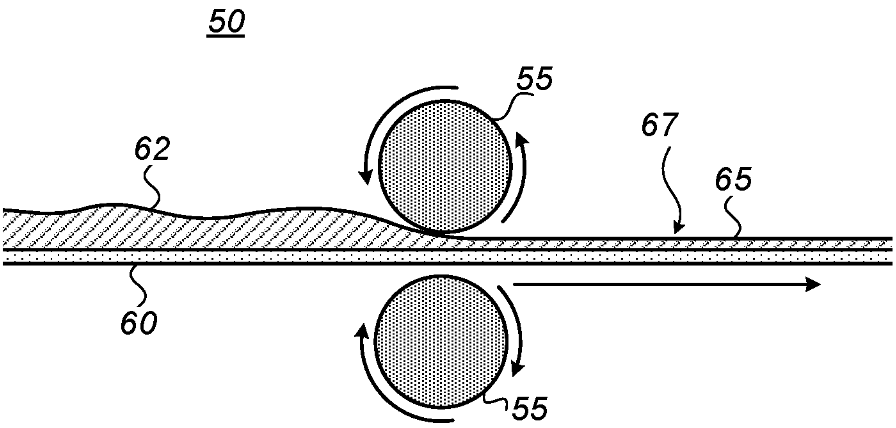


Figure 9 – Prior Art

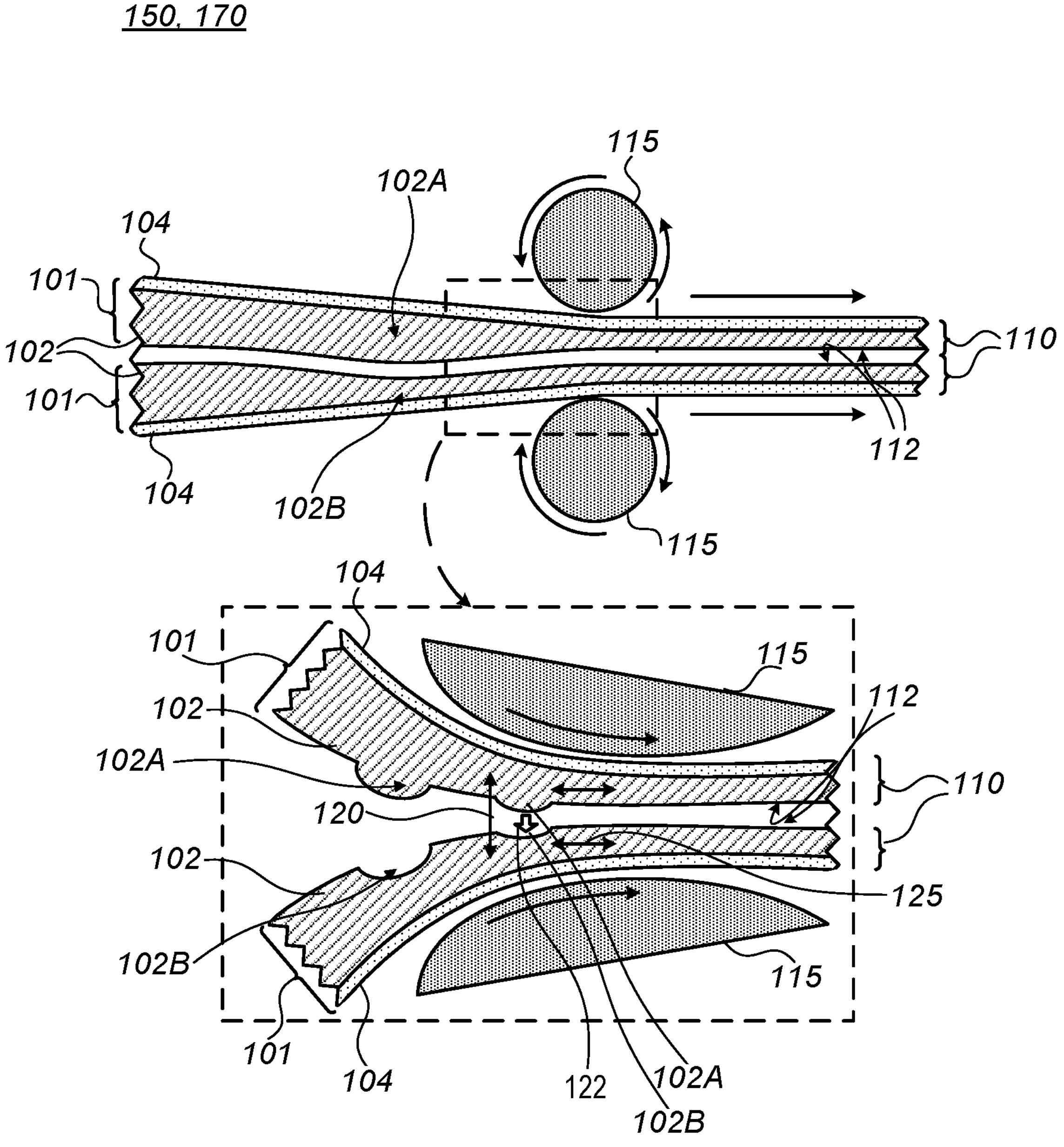

150, 170
115
102A
104
101
102
101
104
102B
110
112
115
104
101
102
102A
120
102
102B
101
104
115
112
110
125
115
122
102A
102B

Figure 10

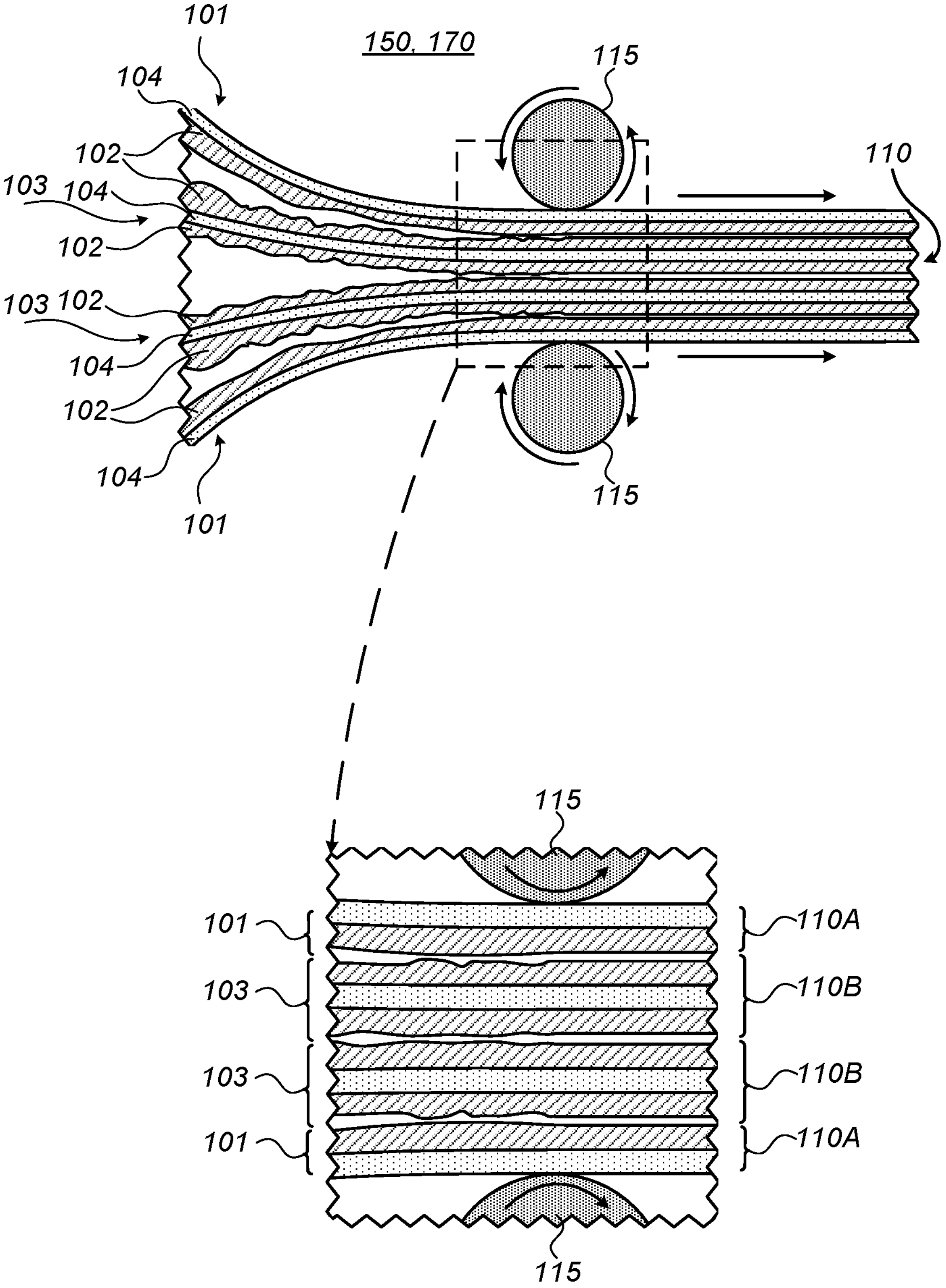

101
150, 170
115
104
102
110
103
104
102
103
102
104
102
104
115
101
115
101
110A
103
110B
103
110B
101
110A
115

Figure 11A

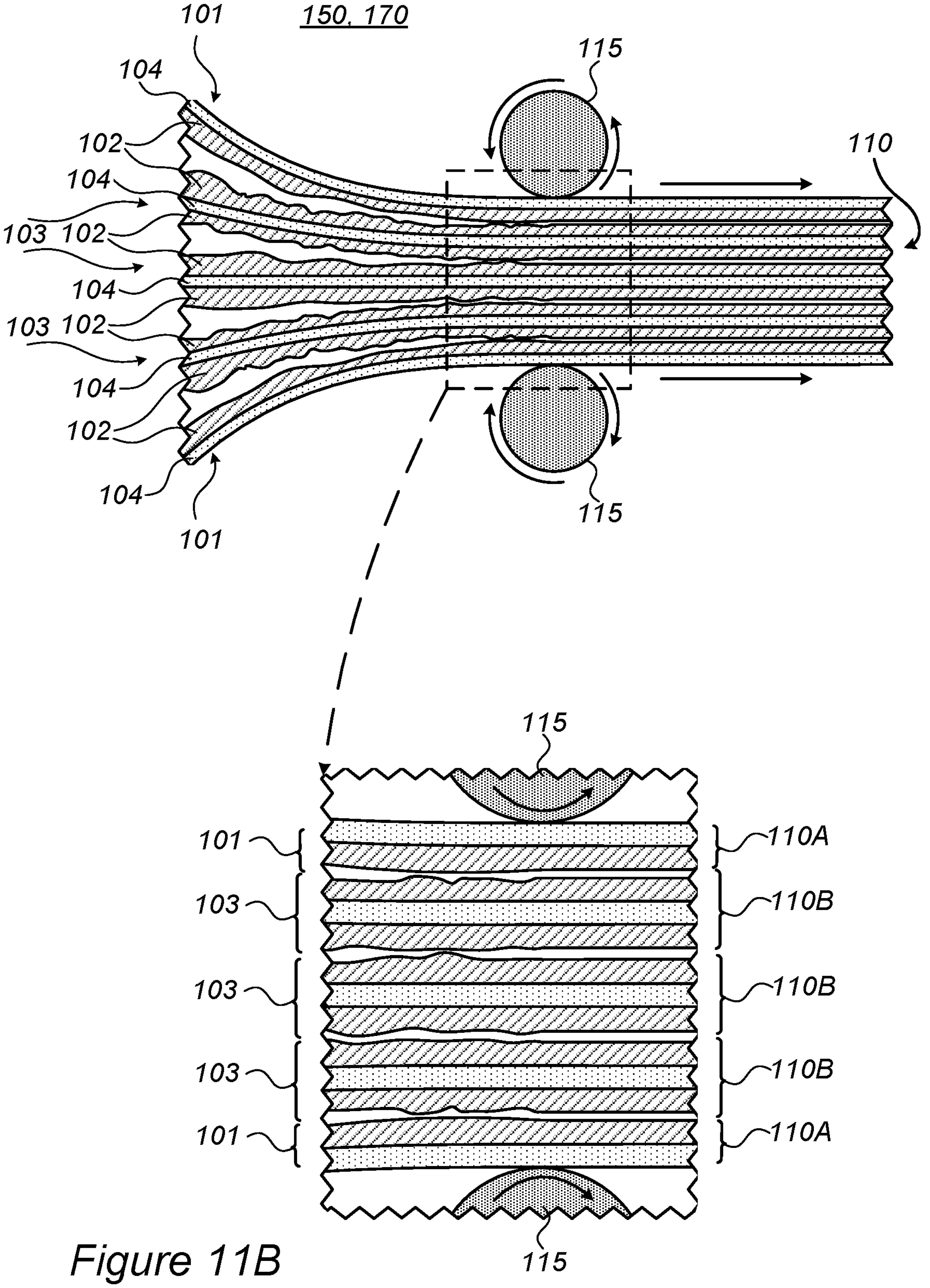

150, 170
101
104
102
104
103
102
104
103
102
104
102
104
101
115
115
110
115
101
103
103
103
101
110A
110B
110B
110B
110A
115

Figure 11B

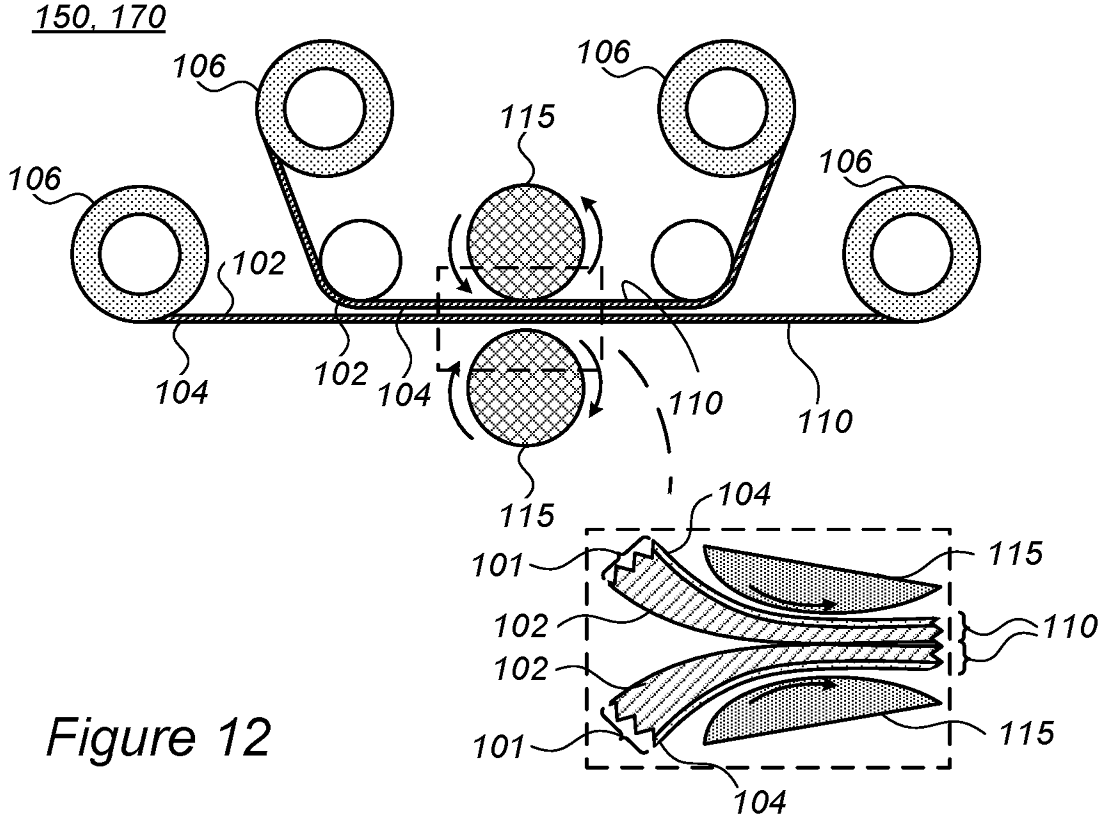


Figure 12

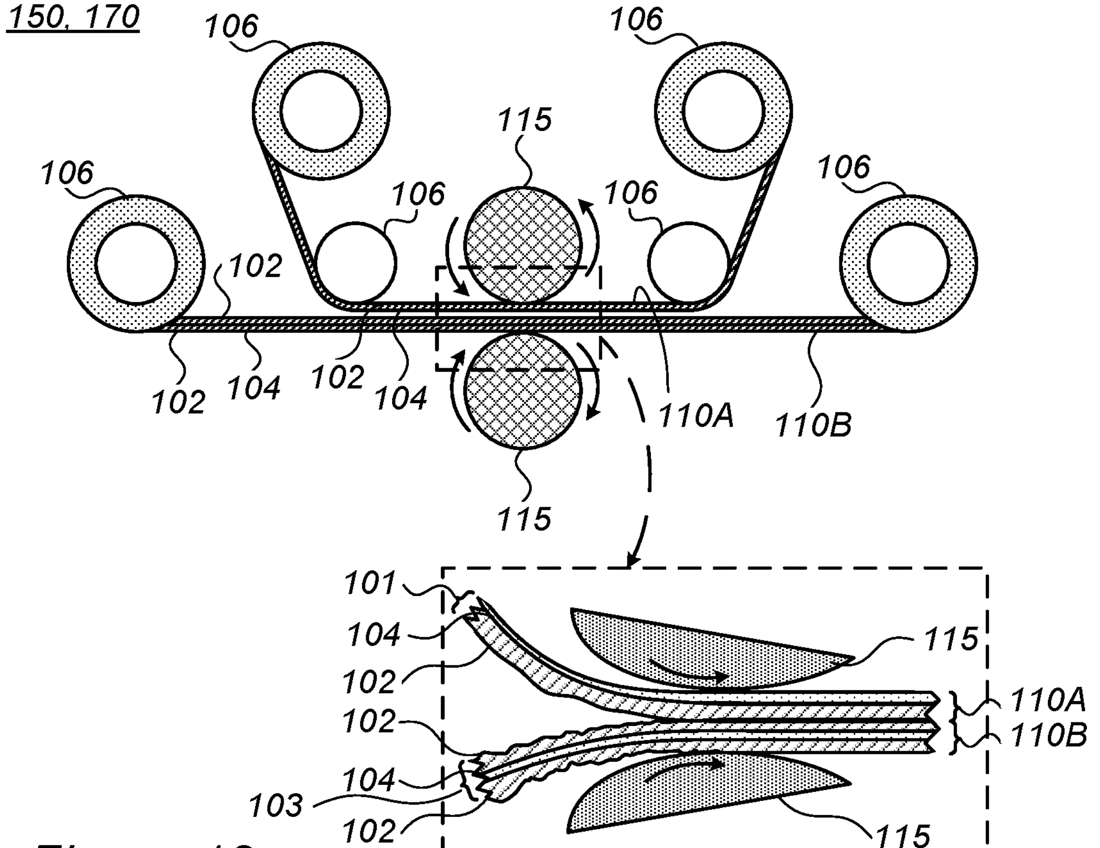


Figure 13

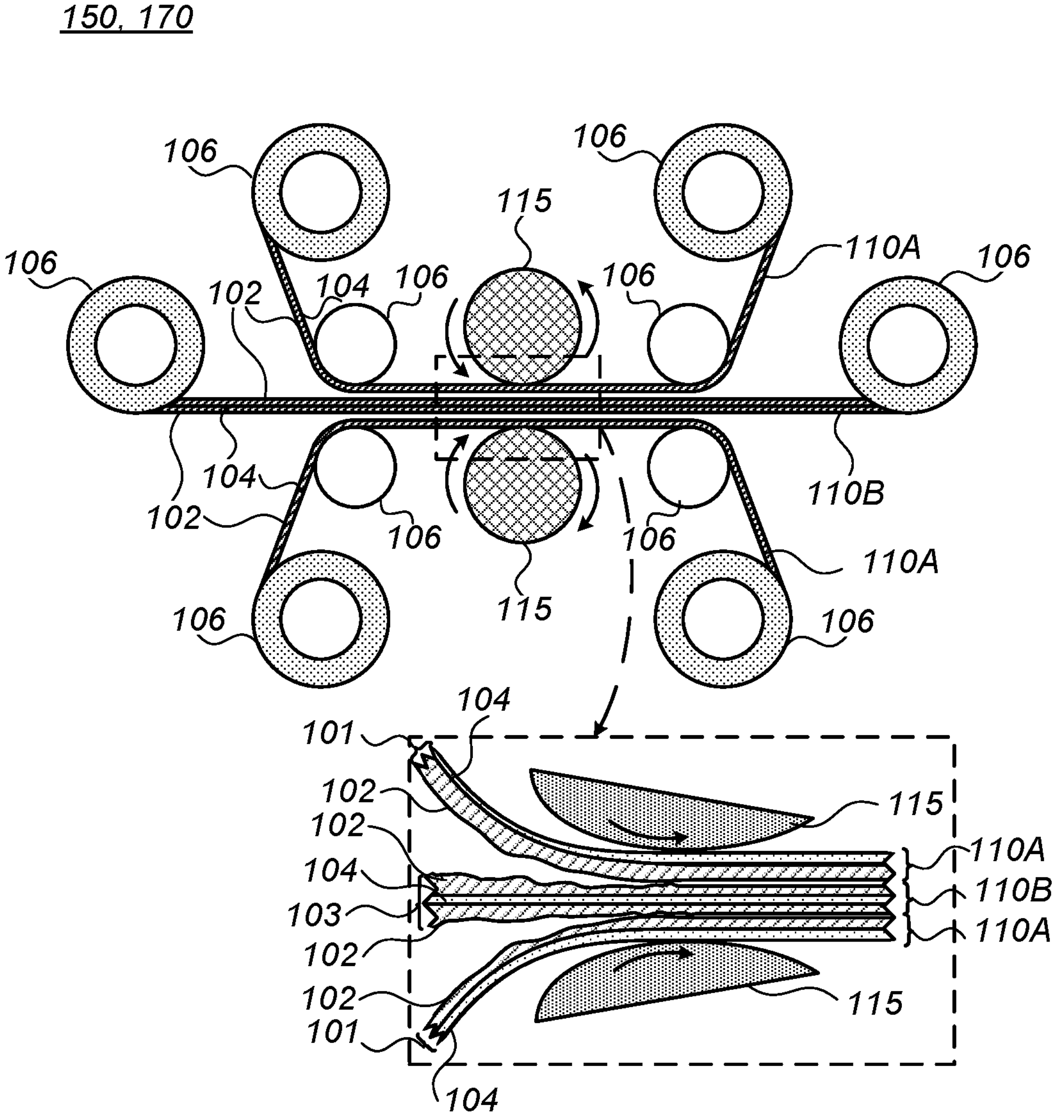

150, 170
106
106
115
110A
106
106
104
106
102
106
104
102
106
106
110B
115
110A
106
106
101
104
102
115
102
110A
104
110B
103
110A
102
102
115
101
104

Figure 14

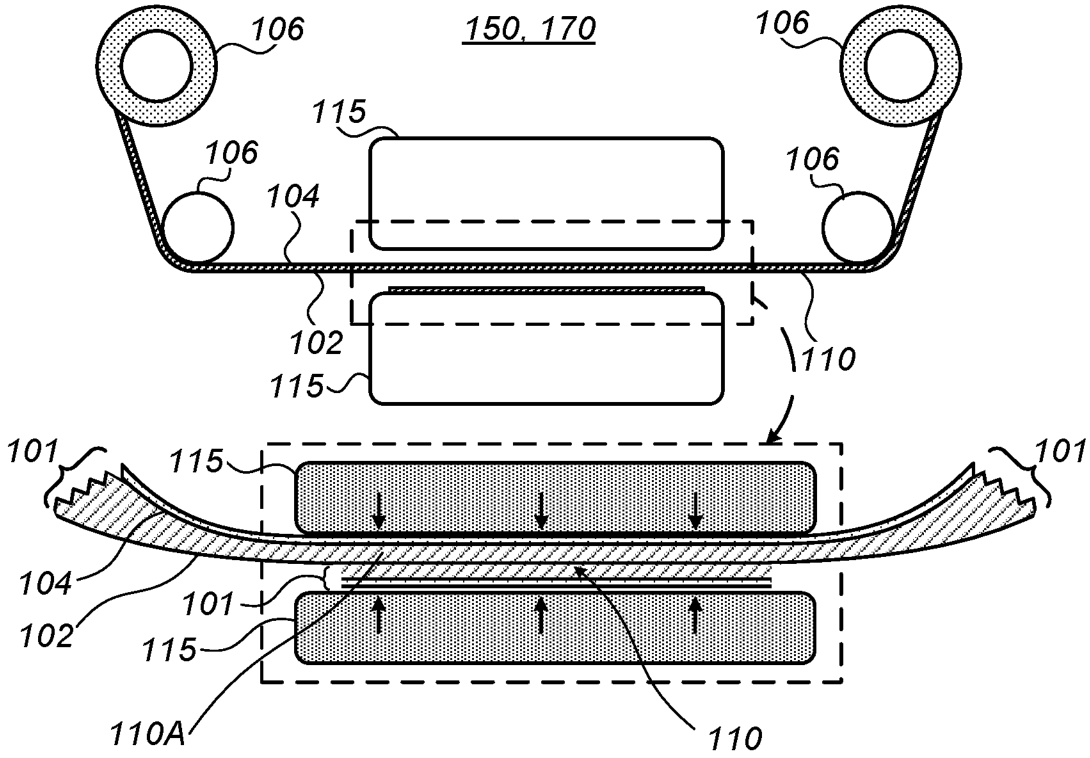


Figure 15

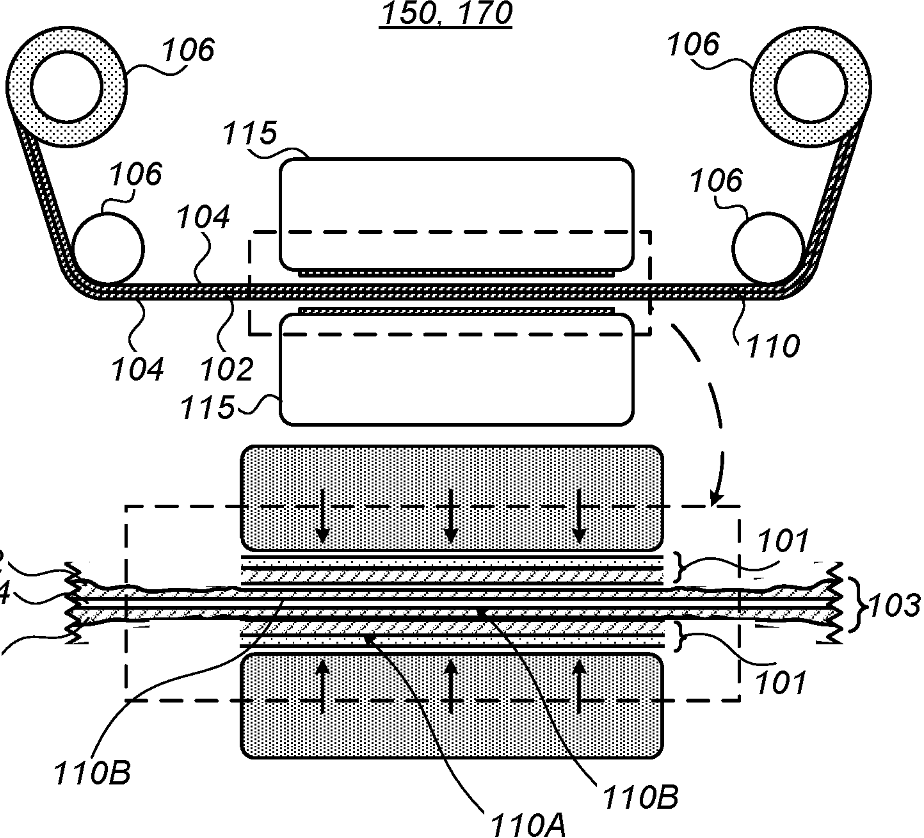


Figure 16

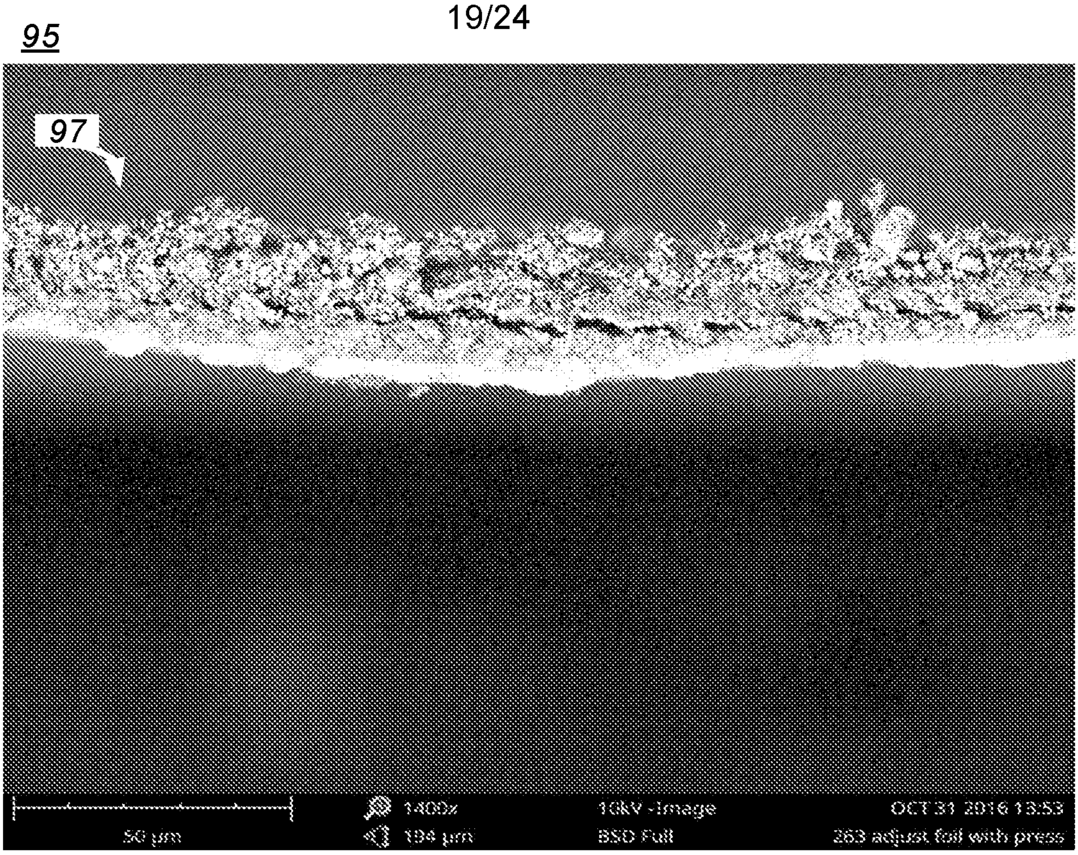


Figure 17A – Prior art

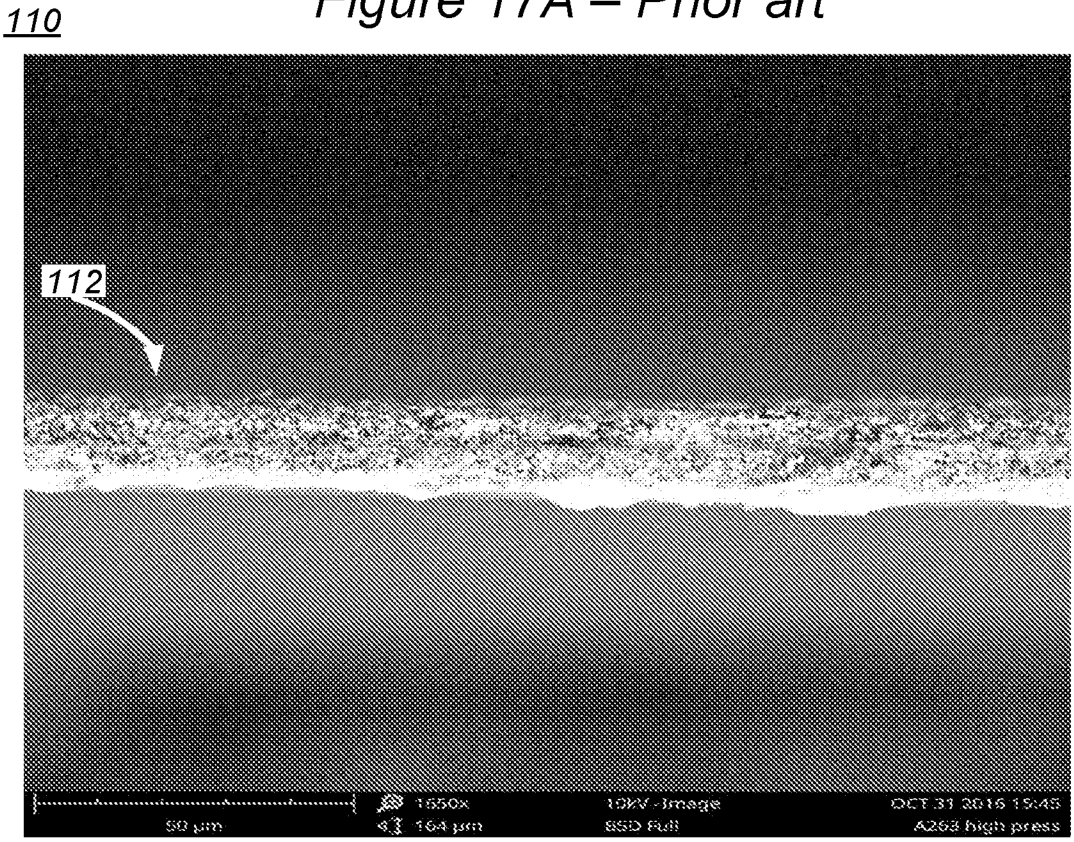


Figure 17B

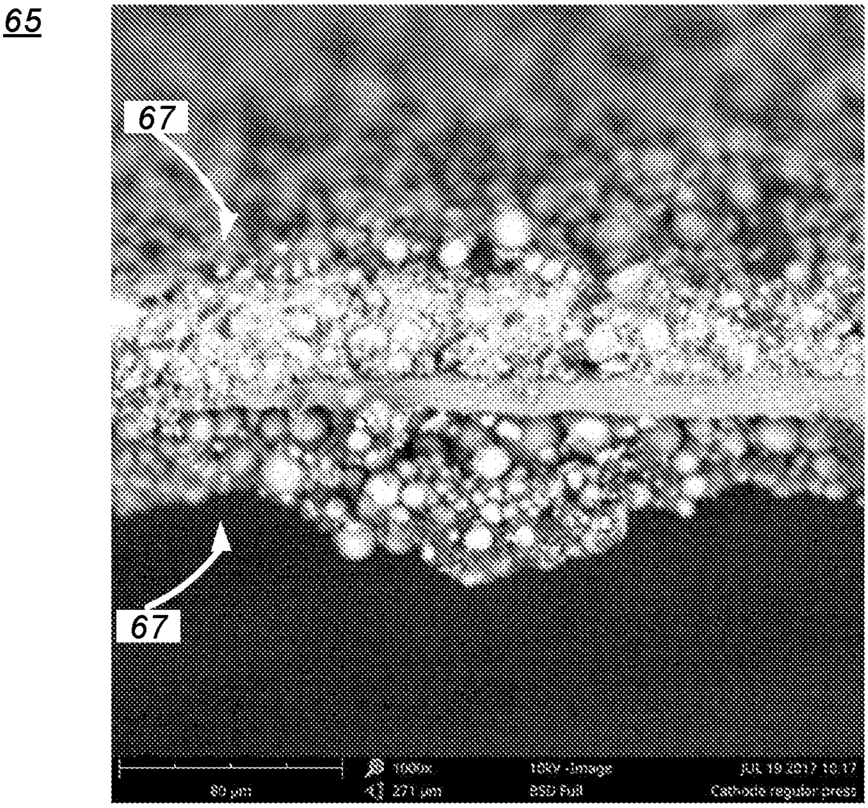


Figure 18A – Prior art

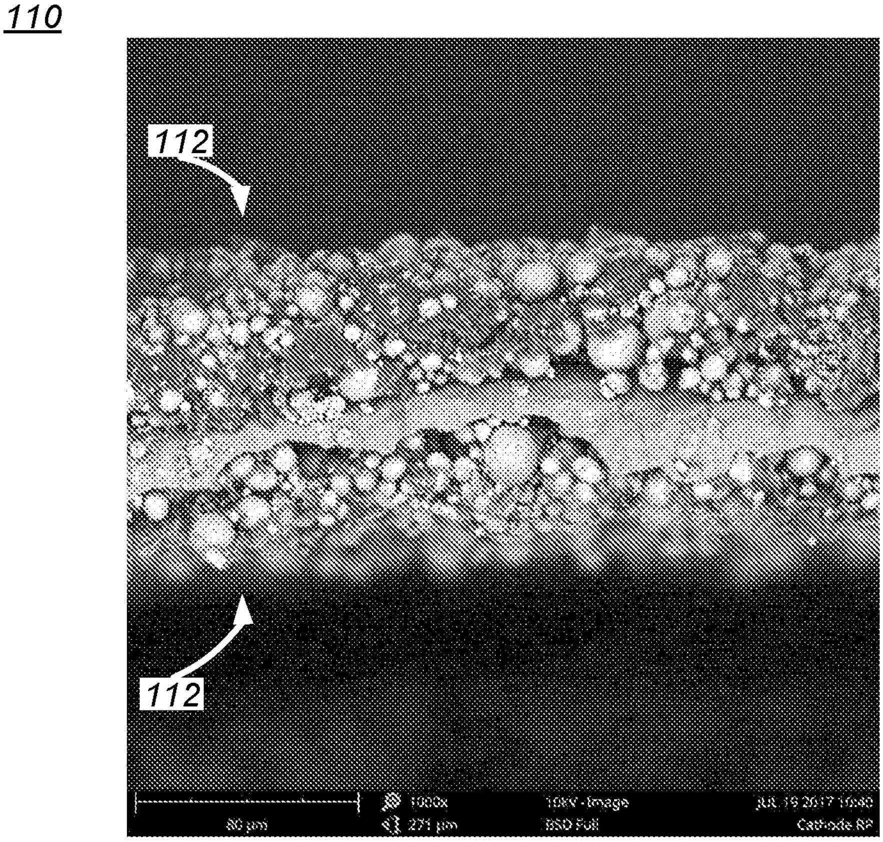


Figure 18B

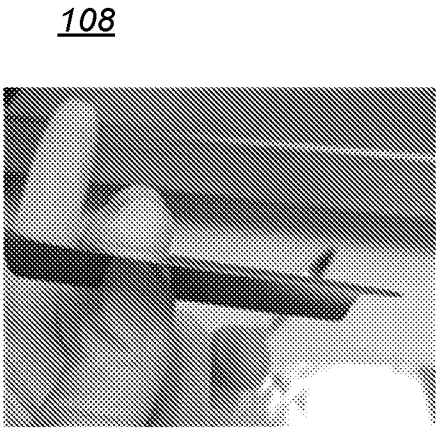


Figure 19A

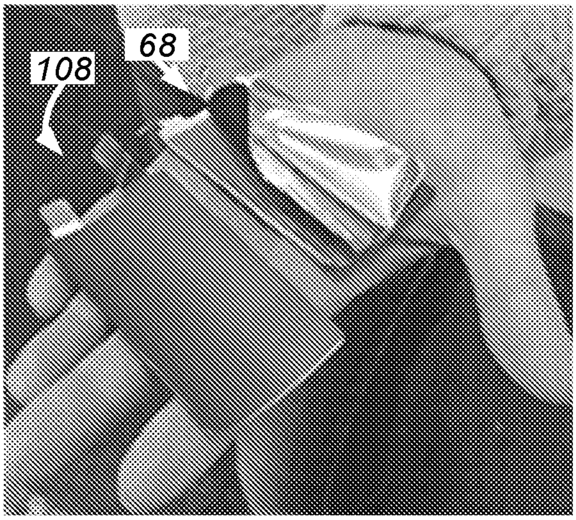


Figure 19B

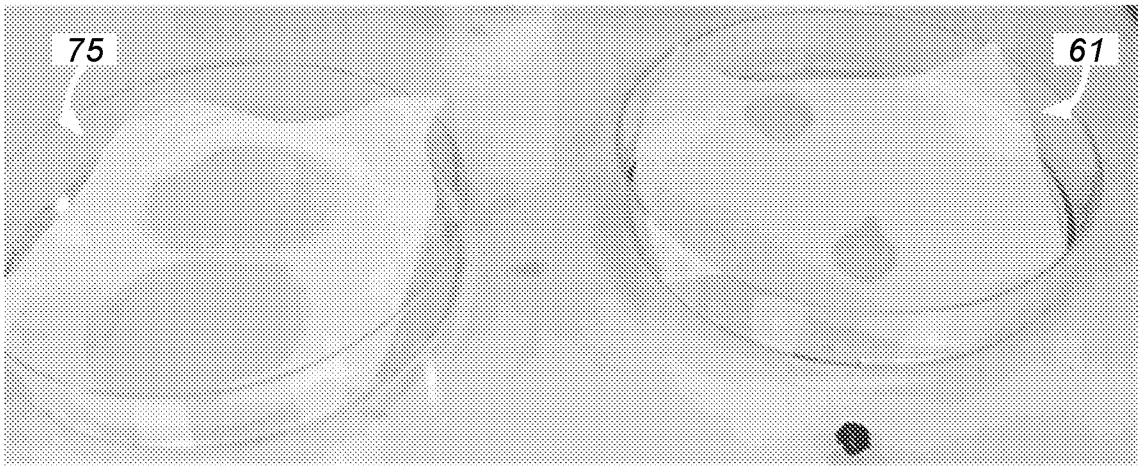


Figure 19C

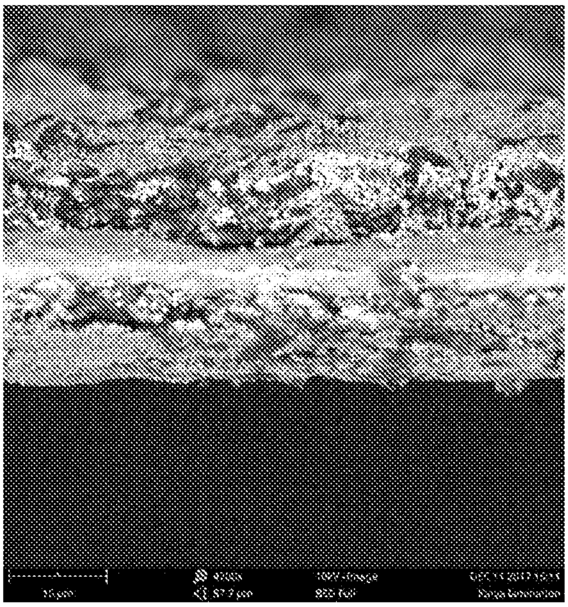


Figure 19D – Prior art

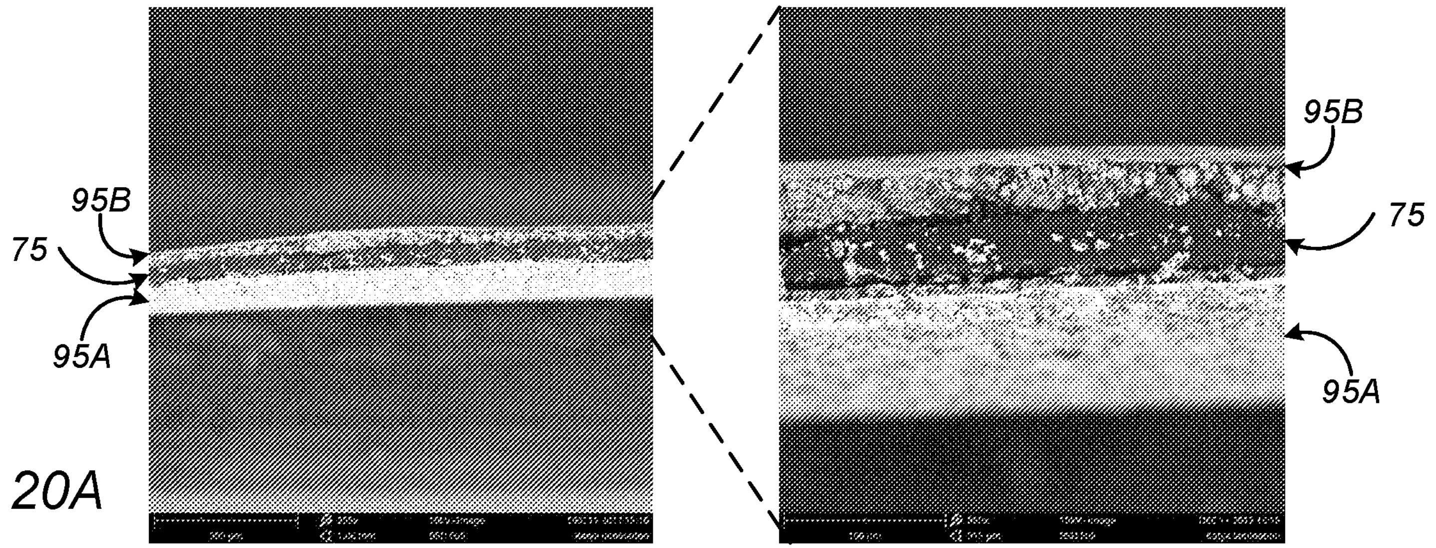


Figure 20A

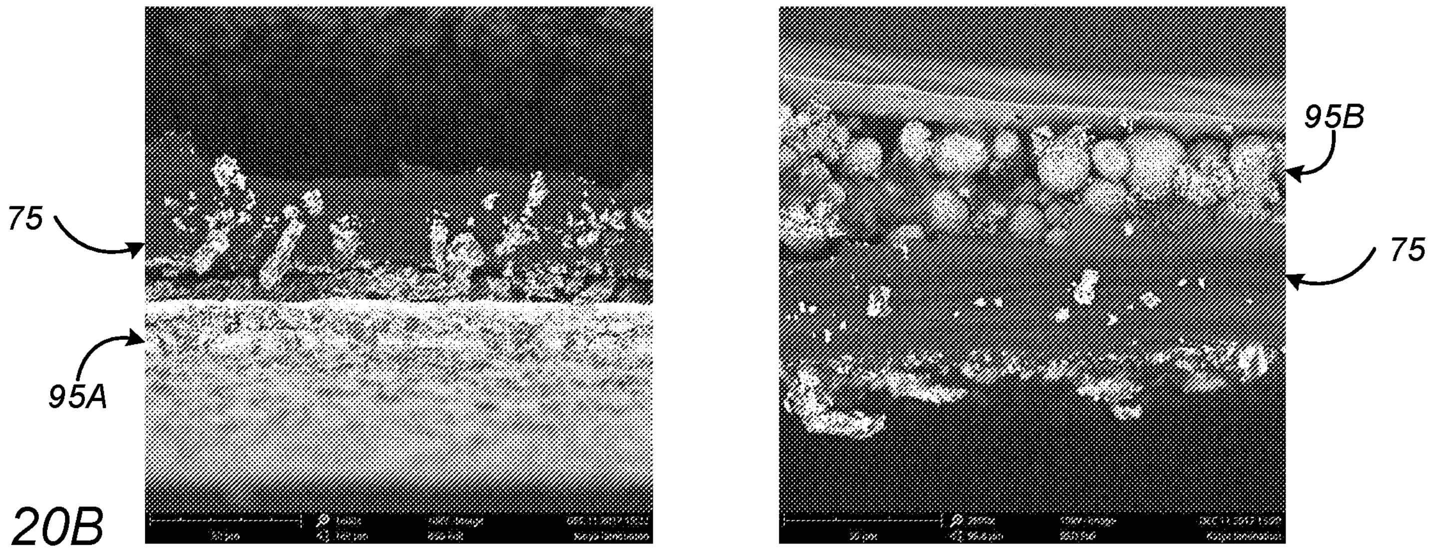
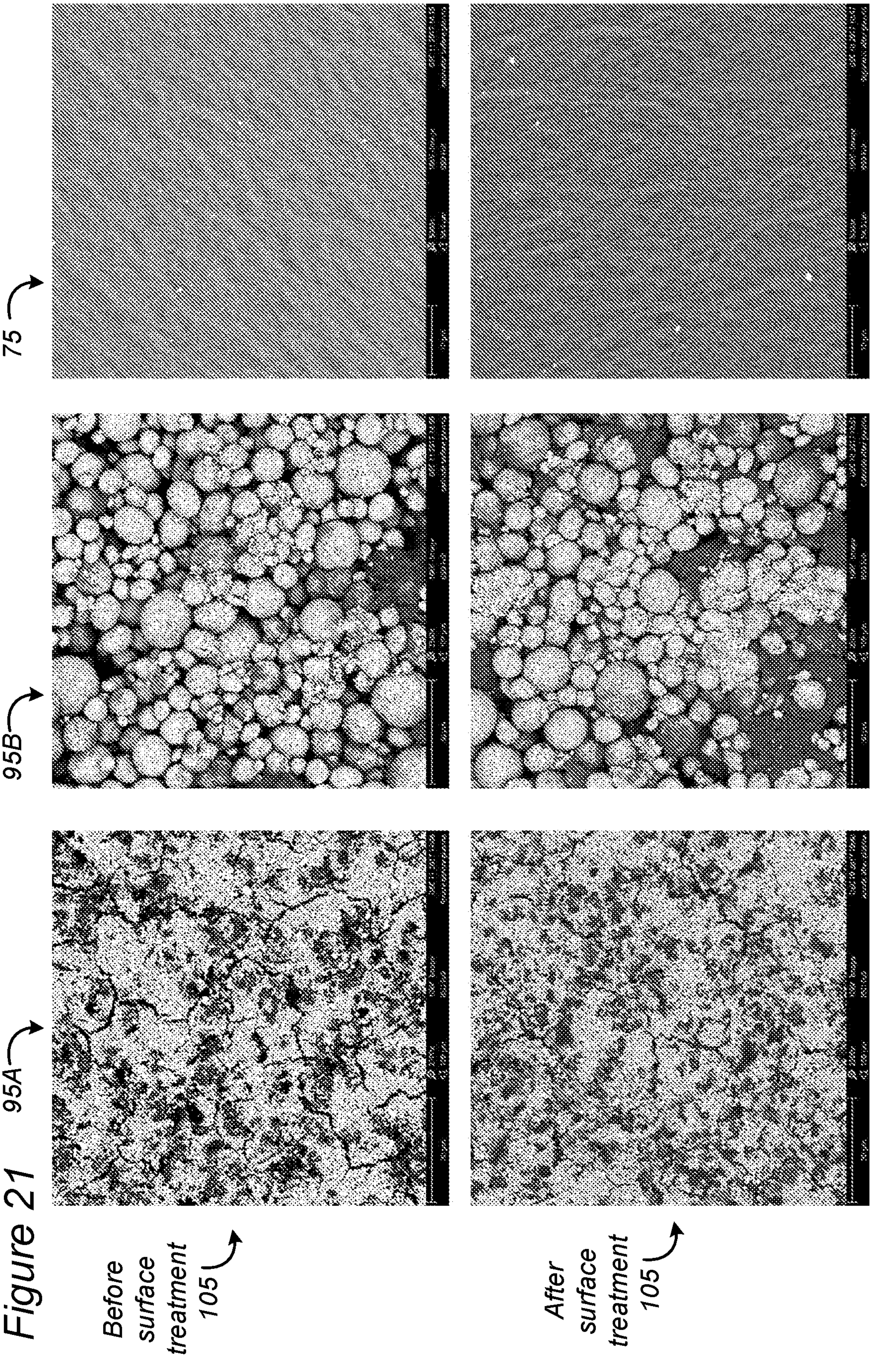


Figure 20B

Figure 21


95A
95B
75
Before surface treatment 105
After surface treatment 105

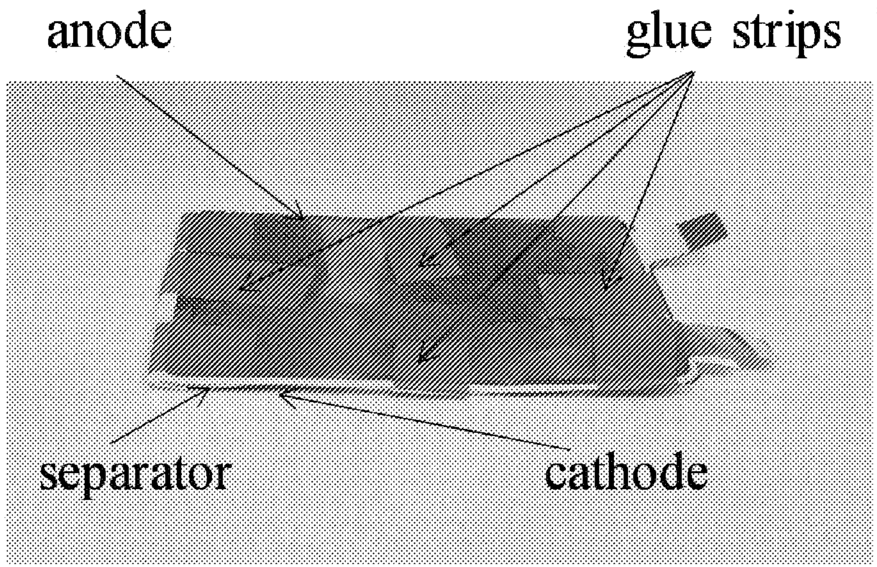


Figure 22A – Prior art

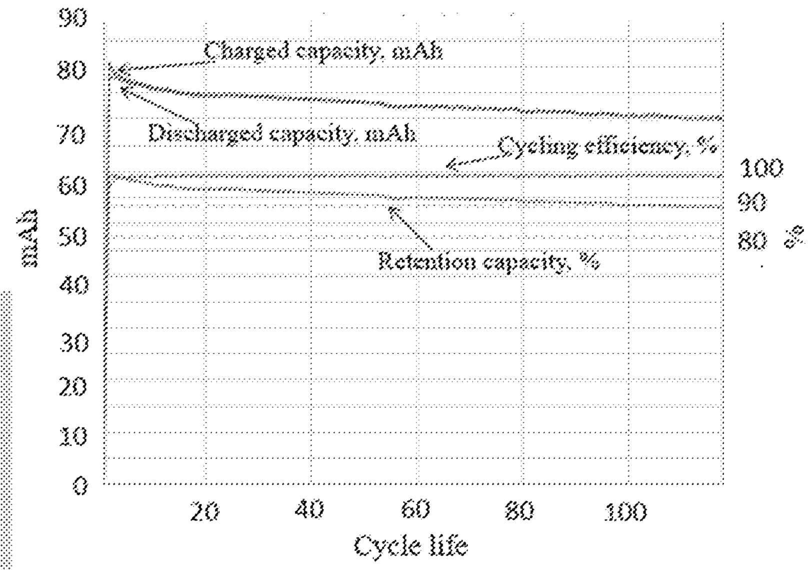


Figure 22B – Prior art

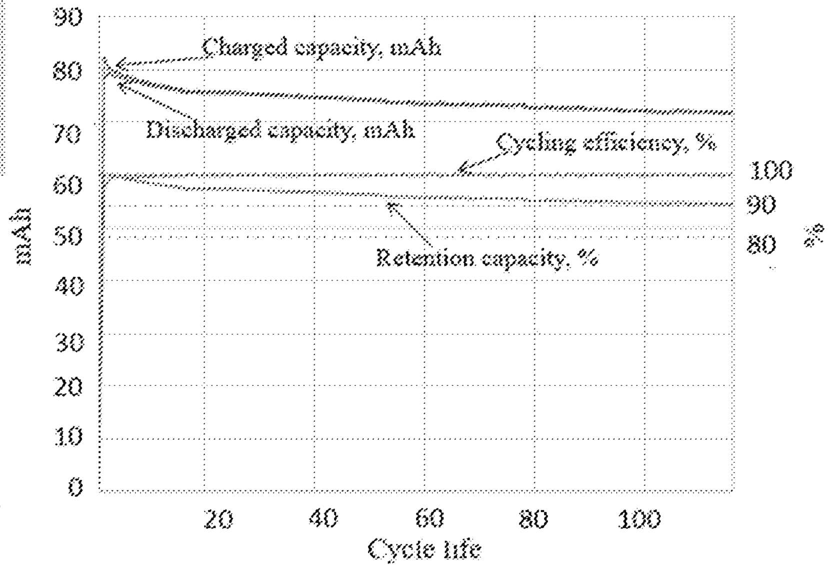


Figure 22C

INTERNATIONAL SEARCH REPORT

International application No.

PCT/IL2017/051359

A. CLASSIFICATION OF SUBJECT MATTER

IPC (2018.01) H01M 10/052, H01M 2/14, H01M 2/16, H01M 10/04

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)

IPC (2018.01) H01M 10/052, H01M 2/14, H01M 2/16, H01M 10/04, H01M 10/052500, H01M 4/88

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)

See extra sheet.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014079994 A1 (SION POWER CORPORATION) 20 Mar 2014 (2014/03/20) The entire document, especially figures 1-3, paragraphs 0020, 0024, 0026, 0032, 0034-0040, 0048, 0050, 0051, 0064, 0074, 0087, 0095, 0098, 0103, 0104, 0108-0111, 0121, 0123	27-38,40-59
A		1-26,39
A	US 2016013468 A1 (LG CHEM, LTD) 14 Jan 2016 (2016/01/14) The entire document	1-26,39
A	US 2011008531 A1 (SION POWER CORPORATION) 13 Jan 2011 (2011/01/13) The entire document	1-26,39
A	HU, Liangbing, et al. Thin, flexible secondary Li-ion paper batteries. ACS nano, 2010, 4.10: 5843-5848. HU, Liangbing, et al. 13 Sep 2010 (2010/09/13)	1-59

☒ 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 27 Mar 2018	Date of mailing of the international search report 27 Mar 2018
Name and mailing address of the ISA: Israel Patent Office Technology Park, Bldg.5, Malcha, Jerusalem, 9695101, Israel Facsimile No. 972-2-5651616	Authorized officer Aamidor Josh Telephone No. 972-2-5651722

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2015357671 A1 (LG CHEM, LTD) 10 Dec 2015 (2015/12/10) The entire document	1-59
A	US 2010209745 A1 (TONEN CHEMICAL CORPORATION) 19 Aug 2010 (2010/08/19) The entire document	1-59
A	US 2014272547 A1 (RAMASUBRAMANIAN MURALI, et al.) 18 Sep 2014 (2014/09/18) The entire document	1-59
A	US 2011177398 A1 (SION POWER CORPORATION) 21 Jul 2011 (2011/07/21) The entire document	1-59
A	US 2014023922 A1 (ISSHIKI YASUHIRO et al.) 23 Jan 2014 (2014/01/23) The entire document	1-59
P,A	US 2017084898 A1 (CELGARD, LLC) 23 Mar 2017 (2017/03/23) The entire document	1-59

B. FIELDS SEARCHED:

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

Databases consulted: Google Patents, PatBase
Search terms used: electrode storage cell cathode anode battery batteries, separate, stack, surface treat bind active, release sacrifice remove, decompose, press calendar compact roll mill, laminate foil coat film layer adhesive, slurry paste, sputter deposit, Li lithium, electrostatic, stabile, current collector, conductive

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IL2017/051359

Patent document cited search report	Publication date	Patent family member(s)	Publication Date
US 2016013468 A1	14 Jan 2016	US 2016013468 A1	14 Jan 2016
		US 9768440 B2	19 Sep 2017
		CN 104718656 A	17 Jun 2015
		CN 104718656 B	12 Apr 2017
		EP 2892102 A1	08 Jul 2015
		EP 2892102 A4	24 Aug 2016
		JP 2015531990 A	05 Nov 2015
		JP 5987119 B2	07 Sep 2016
		KR 20150034328 A	03 Apr 2015
		KR 101609424 B1	05 Apr 2016
		TW 201535829 A	16 Sep 2015
		TW I521765 B	11 Feb 2016
		WO 2015046894 A1	02 Apr 2015
US 2014079994 A1	20 Mar 2014	NONE	
US 2011008531 A1	13 Jan 2011	NONE	
US 2015357671 A1	10 Dec 2015	US 2015357671 A1	10 Dec 2015
		US 9484593 B2	01 Nov 2016
		CN 105393399 A	09 Mar 2016
		CN 105393399 B	09 Mar 2018
		KR 20150050131 A	08 May 2015
		KR 101676406 B1	15 Nov 2016
		WO 2015065127 A1	07 May 2015
US 2010209745 A1	19 Aug 2010	US 2010209745 A1	19 Aug 2010
		US 8414663 B2	09 Apr 2013
		CN 101796108 A	04 Aug 2010
		CN 101796108 B	22 Aug 2012
		JP 2010538097 A	09 Dec 2010

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IL2017/051359

Patent document cited search report	Publication date	Patent family member(s)	Publication Date
		JP 5497635 B2	21 May 2014
		KR 20100082830 A	20 Jul 2010
		KR 101477176 B1	29 Dec 2014
		WO 2009028737 A1	05 Mar 2009
US 2014272547 A1	18 Sep 2014	US 2014272547 A1	18 Sep 2014
		CN 105308772 A	03 Feb 2016
		EP 2973785 A1	20 Jan 2016
		EP 2973785 A4	17 Aug 2016
		HK 1216208 A1	21 Oct 2016
		JP 2016517618 A	16 Jun 2016
		KR 20150128999 A	18 Nov 2015
		TW 201508975 A	01 Mar 2015
		WO 2014151202 A1	25 Sep 2014
US 2011177398 A1	21 Jul 2011	NONE	
US 2014023922 A1	23 Jan 2014	US 2014023922 A1	23 Jan 2014
		US 9306208 B2	05 Apr 2016
		JP WO2012099264 A1	30 Jun 2014
		JP 5904125 B2	13 Apr 2016
		WO 2012099264 A1	26 Jul 2012
US 2017084898 A1	23 Mar 2017	US 2017084898 A1	23 Mar 2017
		WO 2017049065 A1	23 Mar 2017