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(54) **MESH CURRENT COLLECTOR FOR DRY ELECTRODE LAMINATION**

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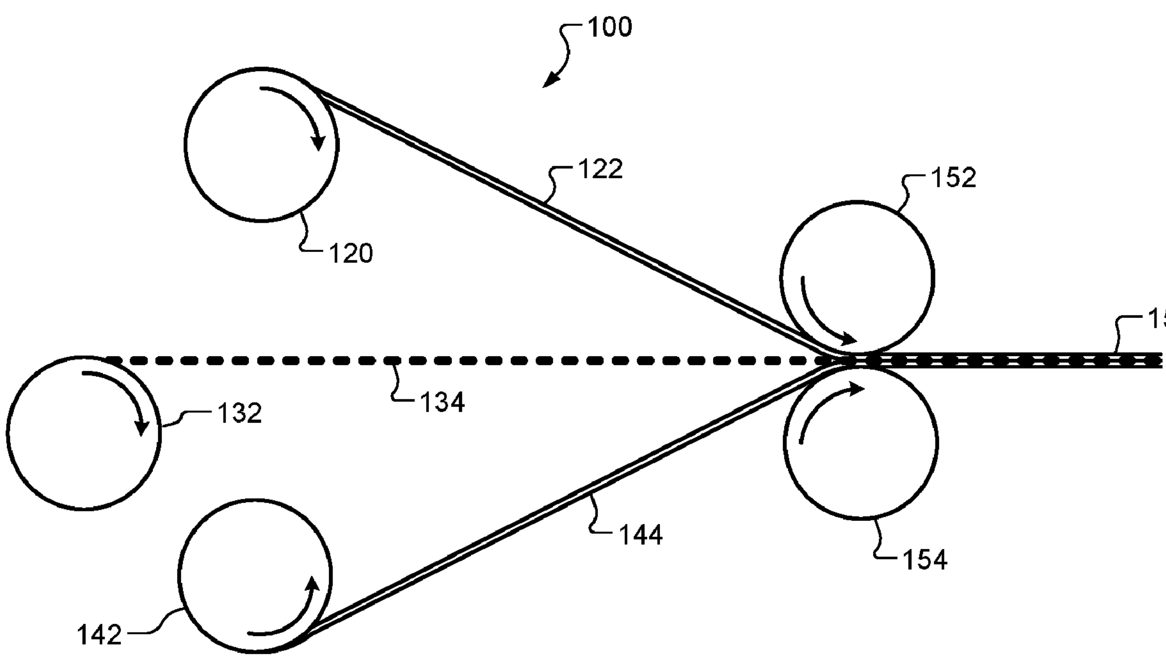
(57) **ABSTRACT**

A method for manufacturing electrodes for a battery cell includes providing a first free-standing electrode; providing a current collector including holes; providing a second free-standing electrode; and laminating the current collector between the first free-standing electrode and the second free-standing electrode using at least one of heat and pressure and without using a solvent.



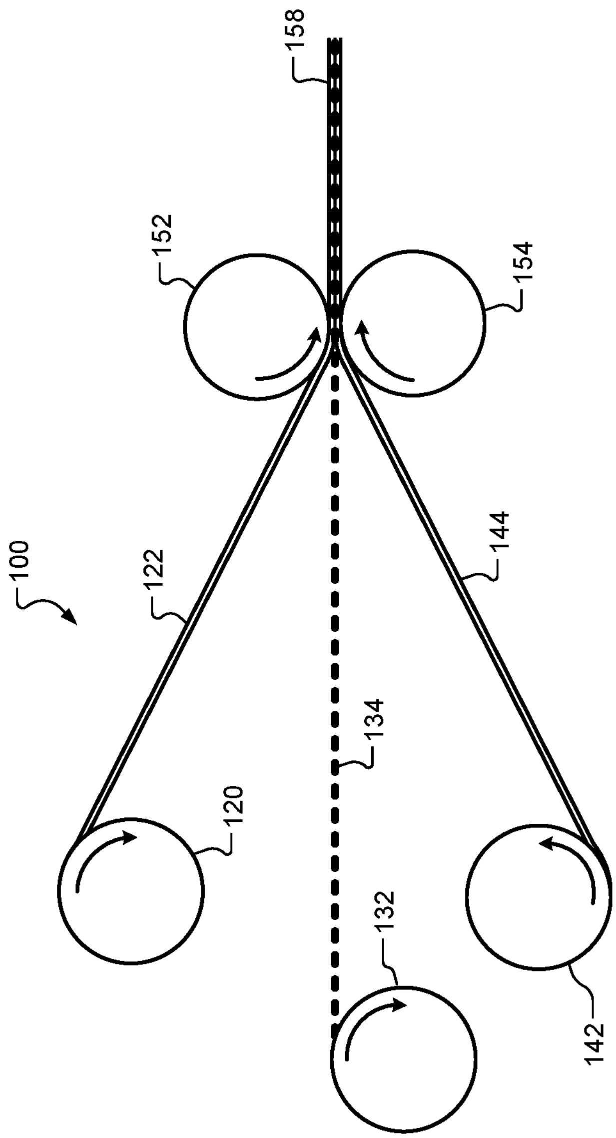


FIG. 1

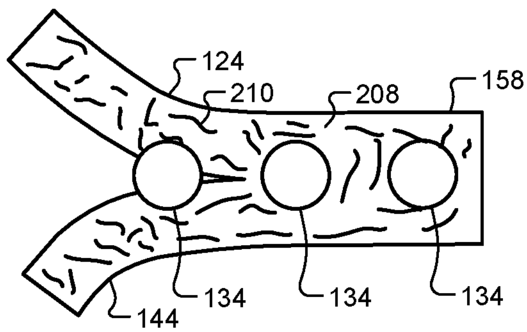


FIG. 2

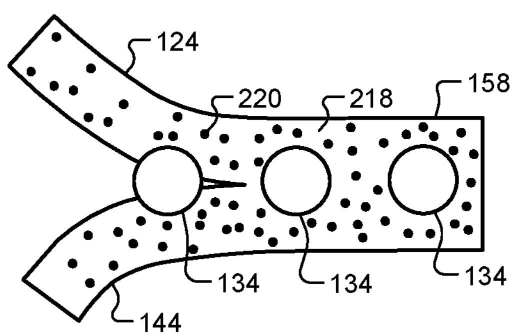


FIG. 3

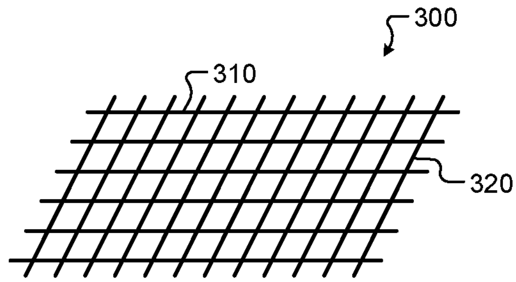


FIG. 4

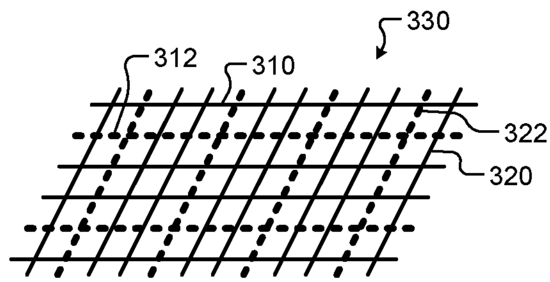


FIG. 5

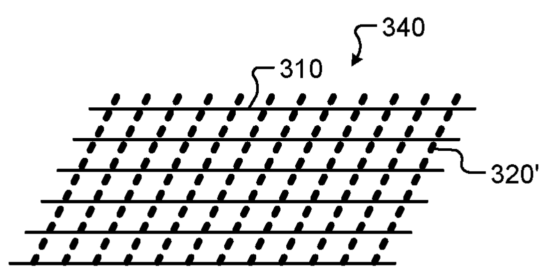


FIG. 6

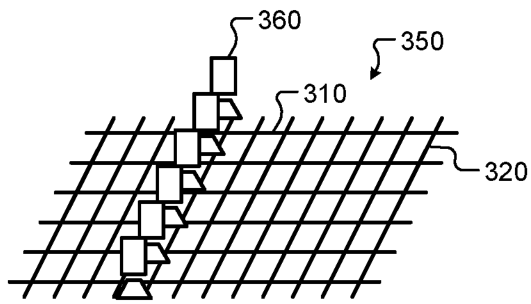


FIG. 7A

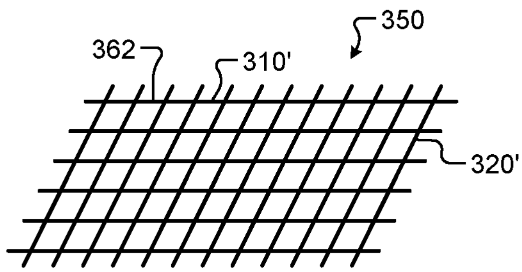


FIG. 7B

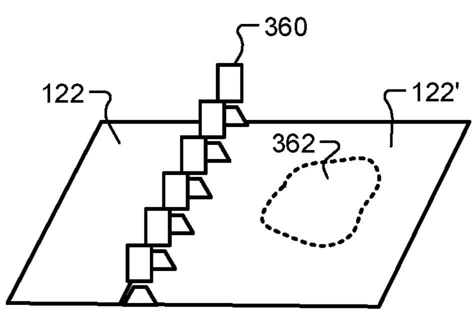


FIG. 8

MESH CURRENT COLLECTOR FOR DRY ELECTRODE LAMINATION

INTRODUCTION

[0001] The information provided in this section is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this section, as well as aspects of the description that may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

[0002] The present disclosure relates to battery cells, and more particularly to a battery cell with a mesh current collector and laminated electrodes.

[0003] Electric vehicles such as battery electric vehicles and hybrid vehicles include a battery pack including one or more battery modules each including one or more battery cells. When manufacturing the battery cells, a slurry including active material, a binder, and/or solvent is applied to opposite sides of a current collector. Use of solvent in the process increases cost, emissions, and a manufacturing footprint.

SUMMARY

[0004] A method for manufacturing electrodes for a battery cell includes providing a first free-standing electrode; providing a current collector including holes; providing a second free-standing electrode; and laminating the current collector between the first free-standing electrode and the second free-standing electrode using at least one of heat and pressure and without using a solvent.

[0005] In other features, the first free-standing electrode and the second free- standing electrode comprises an active material that exchanges lithium ions and a binder selected from a group consisting of polytetrafluoroethylene (PTFE) binder and a thermoplastic polymer binder. The first free-standing electrode and the second free- standing electrode are selected from a group consisting of a dry electrode and a semi- dry electrode. The current collector is made of a material selected from a group consisting of aluminum (Al), copper (Cu), carbon (C) and/or stainless steel.

[0006] In other features, the current collector comprises at least one of metal foam and a wire mesh. The current collector comprises an expanded metal sheet. The current collector comprises a perforated metal sheet. At least some wires of the wire mesh are coated with a binder coating. The binder coating is selected from a group consisting of polytetrafluoroethylene and a thermoplastic polymer. The thermoplastic polymer is selected from a group consisting of polyvinylidene fluoride (PVDF), polyethylene (PE), polypropylene (PP), poly(acrylic acid) (PAA), poly (vinylidene fluoride-co-hexafluoropropylene) (PVDF-HFP), and combinations thereof. At least some wires of the wire mesh are coated with a conductive coating.

[0007] A method for manufacturing electrodes for a battery cell includes providing a first free-standing electrode including an active material that exchanges lithium ions and a binder selected from a group consisting of polytetrafluoroethylene (PTFE) binder and a thermoplastic polymer binder. The first free-standing electrode is selected from group consisting of a dry electrode and a semi-dry electrode. The method includes providing a current collector including holes. The current collector is selected from a group consisting of a wire mesh, metal foam, an expanded metal sheet and a perforated metal sheet. The method includes laminating the current collector to the first free-standing electrode using at least one of heat and pressure and without using a solvent.

[0008] In other features, the current collector comprises the wire mesh and at least some wires of the wire mesh are coated with a binder coating. The binder coating is selected from a group consisting of polytetrafluoroethylene (PTFE) and a thermoplastic polymer. The thermoplastic polymer is selected from a group consisting of polyvinylidene fluoride (PVDF), polyethylene (PE), polypropylene (PP), poly (acrylic acid) (PAA), poly (vinylidene fluoride-co-hexafluoropropylene) (PVDF-HFP), and combinations thereof. The current collector comprises the wire mesh and at least some wires of the wire mesh are coated with a conductive coating.

[0009] A method for manufacturing electrodes for a battery cell includes providing a first free-standing electrode; providing a second free-standing electrode; providing a current collector including holes, wherein the current collector is selected from a group consisting of a wire mesh, an expanded metal sheet and a perforated metal sheet; and laminating the current collector to the first free-standing electrode and the second free-standing electrode using at least one of heat and pressure without using a solvent. The first free-standing electrode comprises an active material that exchanges lithium ions and a binder selected from a group consisting of polytetrafluoroethylene (PTFE) binder and a thermoplastic polymer binder. The first free-standing electrode is selected from group consisting of a dry electrode and a semi-dry electrode.

[0010] In other features, the current collector comprises the wire mesh and at least some wires of the wire mesh are coated with a binder coating. The binder coating is selected from a group consisting of polytetrafluoroethylene and a thermoplastic polymer. The thermoplastic polymer is selected from a group consisting of polyvinylidene fluoride (PVDF), polyethylene (PE), polypropylene (PP), poly (acrylic acid) (PAA), poly (vinylidene fluoride-co-hexafluoropropylene) (PVDF-HFP), and combinations thereof.

[0011] Further areas of applicability of the present disclosure will become apparent from the detailed description, the claims and the drawings. The detailed description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0013] FIG. **1** illustrates an example of a method for manufacturing a battery cell including a mesh current collector and laminated electrodes according to the present disclosure;

[0014] FIG. **2** is a partial side cross-sectional view of an example of a mesh current collector laminated between electrodes including PTFE binder according to the present disclosure;

[0015] FIG. **3** is a partial side cross-sectional view of an example of a mesh current collector laminated between electrodes including a thermoplastic polymer binder according to the present disclosure;

[0016] FIG. **4** is a perspective view of an example of a mesh current collector including interwoven wires according to the present disclosure;

[0017] FIG. **5** is a perspective view of an example of a mesh current collector including blended wires according to the present disclosure;

[0018] FIG. **6** is a perspective view of an example of a mesh current collector including first wires in one direction and second wires in a transverse direction according to the present disclosure;

[0019] FIGS. **7**A and **7**B are perspective views of an example of a mesh current collector including wires that are coated according to the present disclosure; and

[0020] FIG. **8** is a perspective view of a praying device applying a coating onto a surface of the electrode facing the current collector according to the present disclosure.

[0021] In the drawings, reference numbers may be reused to identify similar and/or identical elements.

DETAILED DESCRIPTION

[0022] While a mesh current collector with laminated electrodes is described in the context of battery cells for electric vehicles, the battery cells can be used in stationary applications or other types of applications.

[0023] Battery cells include a plurality of electrodes including anode electrodes and cathode electrodes. The anode electrodes include an anode coating and an anode current collector. The anode coating includes anode active material, solid electrolyte (optional), conductive additive (optional) and a binder. The cathode electrodes include a cathode coating and a cathode current collector. The cathode coating includes a cathode active material, solid electrolyte (optional), conductive additive (optional) and a binder. In some examples, the cathode and anode active materials exchange lithium ions.

[0024] When the electrodes are manufactured using a wet process, a slurry (including the active material, the binder, conductive additive (optional), and solvent) is applied to one or both sides of the current collector. However, the solvent increases cost, manufacturing area, and/or the environmental impact.

[0025] In a dry electrode process, a power mixture including active material, solid electrolyte (optional), conductive additive (optional), and a binder is mixed. The power is pressed and calendared to create a free-standing film. Solvent usage is eliminated and the manufacturing cost for the electrodes can be reduced. Dry electrode processes also enable technologies such as thicker cathodes and/or all solid-state batteries.

[0026] For a dry process, the electrodes are manufactured as free-standing electrodes and then stored on a roll. Then, one or more free-standing electrodes and the current collectors are bonded together using a conductive adhesive, which uses solvent (e.g., N-methyl-pyrrolidone (NMP)). For example, polytetrafluoroethylene (PTFE) may be used as a binder in dry electrode processes. However, PTFE has poor bonding characteristics to other materials. Generally, a conductive adhesive coating is used to bond a PTFE-based dry electrode to the current collector.

[0027] The present disclosure relates to self-standing dry or semi-dry electrodes that are laminated onto one or both sides of a current collector including a plurality of holes. The current collector can be made of a wire mesh, metal foam, an expanded metal, or a perforated metal. The self-standing dry or semi-dry electrodes can include PTFE- based binder or a thermoplastic polymeric binder.

[0028] In some examples, the roll-to-roll process reactivates the binder during lamination of the self-standing electrodes to the current collector (e.g., by applying heat and/or pressure). For example, the PTFE fibrillates during manufacturing of the self-standing electrodes and can be fibrillated again with shear and/or heat applied by the rollers during lamination to the current collector. In other examples, thermoplastic binders melt and flow during manufacturing of the self-standing electrodes and melt and reflow again due to shear and/or heat applied during lamination to the current collector. As a result, an additional adhesive coating is not required.

[0029] The holes in the current collectors (e.g., wire mesh, expanded metal, or perforated metal) enable physical contact to occur between the double-sided electrodes during lamination. As a result, the electrodes and current collector are mechanically supported by both adhesion (electrode to current collector) and cohesion (electrode to electrode) force.

[0030] Referring now to FIG. **1**, a method **100** for manufacturing electrodes including a current collector **134** laminated to one or more self-standing electrodes **122** and **144** is shown. The self-standing electrodes **122** and **144** comprise dry electrodes or semi- dry electrodes. Semi-dry electrodes use substantially less solvent than traditional wet coatings. In some examples, a semi-dry uses at least 30% less solvent than a traditional wet process. In some examples, solvent wt % in a wet process is in a range from 30 wt % to 50 wt % depending on the materials used. With semi-dry electrodes, the solvent wt % is in a range from 1 wt % to 20 wt % (e.g., 10 wt % to 20 wt %).

[0031] A roll **120** supplies the self-standing electrode **122** between rollers **152** and **154**. A roll **132** supplies the current collector **134** between rollers **152** and **154**. A roll **142** supplies the self-standing electrode **144** between rollers **152** and **154**. The current collector **134** is arranged between the self-standing electrodes **122** and **144**. The rollers **152** and **154** apply pressure and/or heat to laminate the electrodes **122** and **144** to opposite sides of the current collector **134** without conductive adhesive or solvent. The electrodes **122** and **144** comprise anode electrodes and/or cathode electrodes.

[0032] The lamination process eliminates the need for an additional adhesive coatings and/or solvents, which reduces costs. Lamination of the current collector **134** to the electrodes **122** and **144** enables direct physical contact between the electrodes **122** and **144** and provides mechanical support by both adhesion (electrode to current collector) and cohesion (electrode to electrode) force.

[0033] In some examples, the current collector **134** is made of a material selected from a group consisting of aluminum (Al), copper (Cu), carbon (C) and/or stainless steel. In some examples, the current collector **134** comprises a wire mesh including interwoven wires. In other examples, the current collector comprises an expanded metal sheet or a perforated metal sheet.

[0034] The electrodes can include both dry and semi-dry electrodes. While double- sided lamination is shown, single-sided lamination of the electrode onto one side of the current collector can be performed. The temperature, pressure and rolling gap of the rollers is selected depending upon the properties of the electrodes and the binder that is used.

[0035] Referring now to FIG. **2**, the current collector **134** is laminated to one or both of the electrodes **122** and **144**. The electrodes **122** and **144** include active material **208** and a binder **210** comprising polytetrafluoroethylene (PTFE). The binder **210** is fibrillated during manufacturing of the self-standing electrodes **122** and **144** and then further fibrillation occurs during lamination to the current collector **134**.

[0036] Referring now to FIG. **3**, the current collector **134** is laminated to one or both of the electrodes **122** and **144**. The electrodes **122** and **144** include active material **218** and a thermoplastic polymer binder **220**. In some examples, the thermoplastic polymer binder **220** includes a material selected from a group consisting of polyvinylidene fluoride (PVDF), polyethylene (PE), polypropylene (PP), poly (acrylic acid) (PAA), poly (vinylidene fluoride-co-hexafluoropropylene) (PVDF-HFP), and combinations thereof. The thermoplastic polymer binder **220** is melted during manufacturing of the self-standing electrodes **122** and **144** and then further melting occurs during lamination to the current collector **134**.

[0037] Referring now to FIG. **4**, a current collector **300** uses the same material for wires **310** arranged in a first direction and wires **320** arranged in a second direction. In some examples, the second direction is transverse to the first direction or more complex patterns can be used.

[0038] Referring now to FIG. **5**, a mesh current collector **330** includes the wires **310** arranged in a first direction and the wires **320** arranged in a second direction. In some examples, the second direction is transverse to the first direction. Some of the wires **310** (e.g., blended wires **312**) are made of a second material that is different than the first material used for the wires **310** or are made of the same or different material and include a coating.

[0039] Some of the wires **320** (e.g., blended wires **322**) are made of a second material that is different than the first material used for the wires **320** or are made of the same or different material and include a coating. While the blended wires **312** and **322** are shown extending in both directions, the blended wires **312** or **322** may be used in one direction or both.

[0040] In some examples, the blended wires **312** and **322** comprise metal wires that are coated with a binder material such as PFTE or a thermoplastic polymer. In other examples, the blended wires **312** and **322** comprise metal wires that are coated with a material to reduce interfacial resistance such as carbon, gold, or another material. The coating can be a dry or wet coating.

[0041] Referring now to FIG. **6**, a mesh current collector **340** includes the wires **310** arranged in a first direction and the wires **320** arranged in a second direction. The wires **320'** are made of a second material that is different than the first material used for the wires **310** or are made of the same or different material but have a coating.

[0042] In some examples, the wires **320'** are coated with a binder material (such as PTFE or a thermoplastic binder material) or a material to reduce interfacial resistance such as carbon, gold, or another material. The coating can be a dry or wet coating.

[0043] Referring now to FIGS. **7**A and **7**B, a mesh current collector **350** includes the wires **310** arranged in a first direction and the wires **320** arranged in a second direction. In FIG. **7**A, a surface treatment device **360** is used to coat the wires **310** and **320**. In FIG. **7**B, wires **310'** and **320'** include a coating **362**. In some examples, the coating comprises a binder material such as PTFE or a thermoplastic binder material or a material to reduce interfacial resistance such as carbon, gold, or another material. The coating can be a dry or wet coating.

[0044] Referring now to FIG. **8**, a surface treatment device **360** applies a coating **362** a surface of the electrode **122** (or **144**) facing the current collector **134**. In some examples, the coating **362** comprises a binder material such as PTFE or a thermoplastic binder material or a material to reduce interfacial resistance such as carbon, gold, or another material. The coating can be a dry or wet coating.

[0045] The foregoing description is merely illustrative in nature and is in no way intended to limit the disclosure, its application, or uses. The broad teachings of the disclosure can be implemented in a variety of forms. Therefore, while this disclosure includes particular examples, the true scope of the disclosure should not be so limited since other modifications will become apparent upon a study of the drawings, the specification, and the following claims. It should be understood that one or more steps within a method may be executed in different order (or concurrently) without altering the principles of the present disclosure. Further, although each of the embodiments is described above as having certain features, any one or more of those features described with respect to any embodiment of the disclosure can be implemented in and/or combined with features of any of the other embodiments, even if that combination is not explicitly described. In other words, the described embodiments are not mutually exclusive, and permutations of one or more embodiments with one another remain within the scope of this disclosure.

What is claimed is:

1. A method for manufacturing electrodes for a battery cell, comprising:

providing a first free-standing electrode;

providing a current collector including holes;

providing a second free-standing electrode; and

laminating the current collector between the first free-standing electrode and the second free-standing electrode using at least one of heat and pressure and without using a solvent.

2. The method of claim **1**, wherein the first free-standing electrode and the second free-standing electrode comprises an active material that exchanges lithium ions and a binder selected from a group consisting of polytetrafluoroethylene (PTFE) binder and a thermoplastic polymer binder.

3. The method of claim **1**, wherein the first free-standing electrode and the second free-standing electrode are selected from a group consisting of a dry electrode and a semi-dry electrode.

4. The method of claim **1**, wherein the current collector is made of a material selected from a group consisting of aluminum (Al), copper (Cu), carbon (C) and/or stainless steel.

5. The method of claim **1**, wherein the current collector comprises at least one of metal foam and a wire mesh.

6. The method of claim **1**, wherein the current collector comprises an expanded metal sheet.

7. The method of claim **1**, wherein the current collector comprises a perforated metal sheet.

8. The method of claim **5**, wherein at least some wires of the wire mesh are coated with a binder coating.

9. The method of claim **8**, wherein the binder coating is selected from a group consisting of polytetrafluoroethylene and a thermoplastic polymer.

10. The method of claim **9**, wherein the thermoplastic polymer is selected from a group consisting of polyvinylidene fluoride (PVDF), polyethylene (PE), polypropylene (PP), poly(acrylic acid) (PAA), poly (vinylidene fluoride-co-hexafluoropropylene) (PVDF-HFP), and combinations thereof.

11. The method of claim **5**, wherein at least some wires of the wire mesh are coated with a conductive coating.

12. A method for manufacturing electrodes for a battery cell, comprising:

providing a first free-standing electrode including an active material that exchanges lithium ions and a binder selected from a group consisting of polytetrafluoroethylene (PTFE) binder and a thermoplastic polymer binder,

wherein the first free-standing electrode is selected from group consisting of a dry electrode and a semi-dry electrode;

providing a current collector including holes,

wherein the current collector is selected from a group consisting of a wire mesh, metal foam, an expanded metal sheet and a perforated metal sheet; and

laminating the current collector to the first free-standing electrode using at least one of heat and pressure and without using a solvent.

13. The method of claim **12**, wherein the current collector comprises the wire mesh and at least some wires of the wire mesh are coated with a binder coating.

14. The method of claim **13**, wherein the binder coating is selected from a group consisting of polytetrafluoroethylene (PTFE) and a thermoplastic polymer.

15. The method of claim **14**, wherein the thermoplastic polymer is selected from a group consisting of polyvinylidene fluoride (PVDF), polyethylene (PE), polypropylene (PP), poly(acrylic acid) (PAA), poly (vinylidene fluoride-co-hexafluoropropylene) (PVDF-HFP), and combinations thereof.

16. The method of claim **12**, wherein the current collector comprises the wire mesh and at least some wires of the wire mesh are coated with a conductive coating.

17. A method for manufacturing electrodes for a battery cell, comprising:

providing a first free-standing electrode;

providing a second free-standing electrode;

providing a current collector including holes, wherein the current collector is selected from a group consisting of a wire mesh, an expanded metal sheet and a perforated metal sheet; and

laminating the current collector to the first free-standing electrode and the second free-standing electrode using at least one of heat and pressure without using a solvent,

wherein the first free-standing electrode comprises an active material that exchanges lithium ions and a binder selected from a group consisting of polytetrafluoroethylene (PTFE) binder and a thermoplastic polymer binder, and

wherein the first free-standing electrode is selected from group consisting of a dry electrode and a semi-dry electrode.

18. The method of claim **17**, wherein the current collector comprises the wire mesh and at least some wires of the wire mesh are coated with a binder coating.

19. The method of claim **17**, wherein the binder coating is selected from a group consisting of polytetrafluoroethylene and a thermoplastic polymer.

20. The method of claim **19**, wherein the thermoplastic polymer is selected from a group consisting of polyvinylidene fluoride (PVDF), polyethylene (PE), polypropylene (PP), poly(acrylic acid) (PAA), poly (vinylidene fluoride-co-hexafluoropropylene) (PVDF-HFP), and combinations thereof.

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