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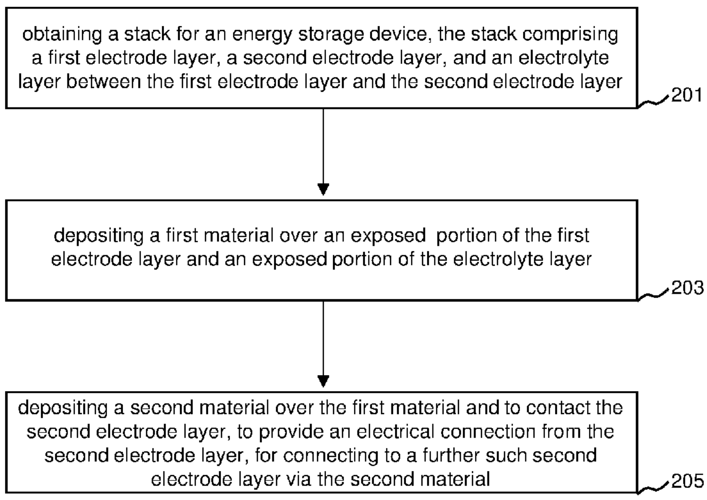

FIG 3

(57) Abstract: A method comprises obtaining a stack for an energy storage device, the stack comprising a first electrode layer, a second electrode layer, and an electrolyte layer between the first electrode layer and the second electrode layer. The method comprises depositing a first material over an exposed portion of the first electrode layer and an exposed portion of the electrolyte layer; and depositing a second material over the first material and to contact the second electrode layer. The second material provides an electrical connection from the second electrode layer, for connecting to a further such second electrode layer via the second material. The first material insulates the exposed portions of the first electrode layer and the electrolyte layer from the second material. Also disclosed is an apparatus.

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STACK FOR AN ENERGY STORAGE DEVICE

Technical Field

The present invention relates to a stack for an energy storage device, and, more specifically, although not exclusively, to methods and apparatus for processing a stack for an energy storage device.

Background

A known method of producing energy storage devices such as solid-state thin film cells comprising layers of electrodes, electrolyte and current collectors is to first form a stack comprising a first current collecting layer formed on a substrate, an electrode layer, an electrolyte layer, a second electrode layer and a second current collecting layer. The stack is then cut into separate sections to form individual cells. Each cell can then be coated with a protective layer, for example, in order to prevent passivation of the layers and possible shorts.

In order to form an electrical connection with the cell, for example in order to electrically connect current collectors of multiple cells stacked one on top of another, part of the protective layer may be removed, for example by etching. Alternatively, a mask can be applied prior to the coating process to ensure that a portion of each current collector is left exposed.

However, known formation and processing of stacks for energy storage devices such as solid-state thin film cells can be inefficient, making effective commercialisation difficult. It is therefore desirable to provide efficient methods for forming and processing of a stack for an energy storage device.

Summary

According to a first aspect of the present invention, there is provided a method comprising: obtaining a stack for an energy storage device, the stack comprising a first electrode layer, a second electrode layer, and an electrolyte layer between the first electrode layer and the second electrode layer; depositing a first material over an exposed portion of the first electrode layer and an exposed portion of the electrolyte layer; and depositing a second material over the first material and to contact the second electrode layer, to provide an electrical connection from the second electrode layer, for connecting to a further such second electrode layer via the second material, whereby the first material insulates the exposed portions of the first electrode layer and the electrolyte layer from the second material.

Depositing the second material over the first material and to contact the second electrode layer may allow for efficient and/or reliable connection of cells formed from the stack in parallel, and hence, for example, for the efficient production of an energy storage device therefrom.

In examples, depositing the first material comprises inkjet material deposition of the first material. Depositing the first material by inkjet material deposition, such as inkjet printing, may allow flexible, efficient, and/or reliable deposition of the first material. For example, inkjet printing may be performed at relatively low (e.g. ambient) temperatures and/or pressures, for example as compared to thermal spray coating, and hence may allow for economic and/or efficient deposition and hence cell production.

In examples, the stack comprises a substrate proximal to one of the first electrode layer and the second electrode layer, wherein the other of the first electrode layer and the second electrode layer is an anode layer. Having the stack in this configuration may allow for anode material to be used as the second material, which may provide for efficient energy storage device production.

In examples, the anode layer comprises anode material, and the second material is the same as the anode material. For example, the anode material may be relatively inexpensive. For example, the anode material may be inexpensive as compared to conductive inks and/or compared to cathode material. Therefore, providing an electrical connection for the anode layer to other such anode layers of further cells using anode material may allow for the cost of the cell production to be reduced, and hence may allow for more efficient cell production. As another example, the deposition of anode material, for example by flood deposition, may be relatively fast and/or inexpensive, for example, as compared to inkjet printing.

In examples, depositing the second material comprises depositing the second material over the anode layer. This may allow for efficient deposition of the second material, and hence efficient cell production. For example, depositing anode material may allow for the anode layer of the obtained stack to be only partially formed, and for the deposited anode material to complete the anode layer. This may reduce the total amount of conductive and/or anode material used in order to produce a cell from the stack.

In examples, depositing the second material comprises inkjet material deposition of the second material. Depositing the second material by inkjet material deposition, such as inkjet printing, may allow flexible, efficient, and/or reliable deposition of the first material. For example, inkjet printing may be performed at relatively low (e.g. ambient) temperatures and/or pressures, for example as compared to thermal spray coating, and hence may allow for economic and/or efficient deposition and hence cell production.

In examples, the first electrode layer, the electrolyte layer, and the second electrode layer are recessed from the substrate so that the substrate provides a ledge portion on which the first material and/or the second material is/are at least partially supported. Having a ledge portion may allow for the first material and/or the second material to be supported during and/or after deposition, and/or may prevent or reduce unwanted migration of the first material and/or second material, which may in turn facilitate the accurate deposition of the first material and/or the second material.

In examples, the first electrode layer and the electrolyte layer are recessed from the second electrode layer so that the second electrode layer provides a ledge portion on which the first material and/or the second material is/are at least partially supported. Having a ledge portion may allow for the first material and/or the second material to be supported during and/or after deposition, and/or may prevent or reduce unwanted migration of the first material and/or second material, which may in turn facilitate the accurate deposition of the first material and/or the second material.

In examples, the further such second electrode layer is of a further such stack. This may provide for separate cells, formed from the stacks, to be connected in parallel. Connecting cells in parallel may provide for an energy storage device having relatively large discharge rates, which may be useful in some applications.

In examples, the stack comprises a said further second electrode layer, and a further electrolyte layer between the further second electrode layer electrode layer and the first electrode layer, and depositing the first material further comprises depositing the first material over an exposed portion of the further electrolyte layer, and depositing the second material further comprises depositing the second material to contact the further second electrode layer, thereby to connect the second electrode layer and the further second electrode layer via the second material, whereby the first material further insulates the exposed portion of the further electrolyte layer from the second material. Such a stack arrangement may provide for layers that constitute multiple cells on one substrate. This may be an efficient arrangement as it may allow for the amount of substrate, anode and/or cathode material required to form multiple cells to be reduced.

In examples, the electrolyte layer, the first electrode layer, the further electrolyte layer, and the further second electrode layer are recessed from the second electrode layer such that the second electrode layer provides a ledge on which the first material and/or the second material is/are supported. Having a ledge portion may allow for the first material and/or the second material to be supported during and/or after deposition, and/or may prevent or reduce unwanted migration of the first material and/or second material, which may in turn facilitate the accurate deposition of the first material and/or the second material

In examples, the method comprises laser ablating the stack, and one or more of the exposed portions are exposed by the laser ablating of the stack. Laser ablating may provide an effective, reliable, rapid and efficient way to expose the portions of the stack to allow for the connection of the cells formed therefrom, and hence may, in turn, provide for efficient energy storage device production.

According to a second aspect of the present invention, there is provided a stack for an energy storage device, the stack comprising a first electrode layer, a second electrode layer, and an electrolyte layer between the first electrode layer and the second electrode layer, the stack comprising a first material over a portion of the first electrode layer and a portion of the electrolyte layer; and a second material over the first material and contacting the second electrode layer to provide an electrical connection from the second electrode layer, for connecting to a further such second electrode layer via the second material, wherein the first material insulates the portions of the first electrode layer and the electrolyte layer from the second material.

According to a third aspect of the present invention, there is provided an energy storage device formed according to the method according to the first aspect.

Further features and advantages of the invention will become apparent from the following description of preferred embodiments of the invention, given by way of example only, which is made with reference to the accompanying drawings.

Brief Description of the Drawings

Figure 1 is a schematic diagram that illustrates a stack for an energy storage device according to examples;

Figure 2 is a schematic diagram that illustrates one way of processing the stack of Figure 1 for the manufacture of an energy storage device according to examples;

Figure 3 is a flow diagram that illustrates a method of processing a stack according to an example;

Figures 4 and 5 are schematic diagrams that illustrate one way of processing a stack according to a first example;

Figures 6 and 7 are schematic diagrams that illustrate one way of processing a stack according to a second example;

Figures 8 and 9 are schematic diagrams that illustrate one way of processing a stack according to a third example;

Figures 10 and 11 are schematic diagrams that illustrate one way of processing a stack according to a fourth example; and

Figures 12 and 13 are schematic diagrams that illustrate one way of processing a stack according to a fifth example.

Detailed Description

Details of methods, structures and devices according to examples will become apparent from the following description, with reference to the Figures. In this description, for the purpose of explanation, numerous specific details of certain examples are set forth. Reference in the specification to "an example" or similar language means that a particular feature, structure, or characteristic described in connection with the example is included in at least that one example, but not necessarily in other examples. It should further be noted that certain examples are described schematically with certain features omitted and/or necessarily simplified for ease of explanation and understanding of the concepts underlying the examples.

Figure 1 shows a stack 100 of layers for an energy storage device. The stack 100 of Figure 1 may be used as part of a thin film energy storage device having a solid electrolyte, for example.

The stack 100 comprises a substrate 102, a cathode layer 104, an electrolyte layer 106 and an anode layer 108. In the example of Figure 1, the anode layer 108 is further from the substrate 102 than the cathode layer 104, and the electrolyte layer 106 is between the cathode layer 104 and the anode layer 108. The substrate 102 contacts the cathode layer 104 and supports the stack. While in this example the substrate 102 contacts the cathode layer 104, in other examples there may be additional layers (not shown) in between the substrate 102 and the cathode layer 104.

In some examples, the substrate 102 may be or comprise nickel foil; but it will be appreciated that any suitable metal could be used, such as aluminium, copper or steel, or a metallised material including metallised plastics such as aluminium on polyethylene terephthalate (PET). In some examples, the substrate 102 may not be metallic and/or may not conduct electrical current. For example, in some examples, the substrate may be polyethylene terephthalate (PET).

The cathode layer 104 may act as a positive current collecting layer. The cathode layer 104 may form a positive electrode layer (i.e. that corresponds to a cathode during discharge of a cell of an energy storage device including the stack 100). The cathode layer 104 may comprise a material which is suitable for storing Lithium ions by virtue of stable chemical reactions, such as Lithium Cobalt Oxide, Lithium Iron Phosphate or alkali metal polysulphide salts.

The anode layer 108 may act as a negative current collecting layer. The anode layer 108 may form a negative electrode layer (i.e. that corresponds to an anode during discharge of a cell of the energy storage device including the stack 100). The anode layer 108 may comprise a Lithium metal, Graphite, Silicon or Indium Tin Oxides.

In some examples, the anode layer 108 may comprise a negative current collector and a separate negative electrode layer (not shown). In these examples, the negative electrode layer may comprise a Lithium metal, Graphite, Silicon or Indium Tin Oxides, and/or the negative current collector may comprise nickel foil. However, it will be appreciated that any suitable metal could be used, such as aluminium, copper or steel, or a metallised material including metallised plastics such as aluminium on polyethylene terephthalate (PET).

The electrolyte layer 106 may include any suitable material which is ionically conductive, but which is also an electrical insulator such as lithium phosphorous oxynitride (LiPON). The electrolyte layer 106 may be a solid layer, and may be referred to as a fast ion conductor. A solid electrolyte layer may have structure which is intermediate between that of a liquid electrolyte, which for example lacks a regular structure and includes ions which may move freely, and that of a crystalline solid. A crystalline material for example has a regular structure, with an ordered arrangement of atoms, which may be arranged as a two-dimensional or three-dimensional lattice. Ions of a crystalline material are typically immobile and may therefore be unable to move freely throughout the material.

The stack 100 may for example be manufactured by depositing the cathode layer 104 on the substrate 102. The electrolyte layer 106 is subsequently deposited on the cathode layer 104, and the anode layer 108 is then deposited on the electrolyte layer 106. Each layer of the stack 100 may be deposited by vapor deposition, for example physical vapor deposition, for example flood deposition, which provides a simple and effective way of producing a highly homogenous layer, although other deposition methods are possible.

The stack 100 of Figure 1 may undergo processing to manufacture an energy storage device.

A general overview of an example of processing that may be applied to the stack 100 of Figure 1 is illustrated schematically in Figure 2.

In Figure 2, the stack 100 is processed for the manufacture of an energy storage device. The stack 100 in this example is flexible, allowing it to be wound around a roller 112, for example, as part of a roll-to-roll manufacturing process (sometimes referred to as a reel-to-reel manufacturing process). The stack 100 may be gradually unwound from the roller 112 and subjected to processing.

In the example of Figure 2, cuts or grooves may be formed in the stack 100 using a first laser 114. The first laser 114 is arranged to apply laser beams 116 to the stack 100 to remove portions of the stack 100 by laser ablation, thereby forming the cuts or grooves.

After formation of the cuts or grooves, electrically insulating material may be introduced into or into the region of at least some of the cuts or grooves using an insulating material system 118. An electrically insulating material may be considered to be electrically non-conductive and may therefore conduct a relatively a small amount of electric current when subjected to an electric field. Typically, electrically insulating material (sometimes referred to as an insulator) conducts less electric current than semiconducting materials or electrically conductive materials. However, a small amount of electric current may nevertheless flow through an electrically insulating material under the influence of an electric field, as even an insulator may include a small amount of charge carriers for carrying electric current. In examples herein, a material may be considered to be electrically insulating where it is sufficiently electrically insulating to perform the function of an insulator. This function may be performed for example where the material insulates one element from another sufficiently for short-circuits to be avoided.

Referring to Figure 2, after introduction of the electrically insulating material, the stack 110 is cut to form separate cells for an energy storage device. In some examples, hundreds and potentially thousands of cells can be cut from a roll of the stack 100, allowing multiple cells to be manufactured in an efficient manner.

In Figure 2, the cutting operation is performed using a second laser 122, which is arranged to apply laser beams 124 to the stack 100. Each cut may for example be through the centre of an insulating plug such that the plug is split into two pieces, each piece forming a protective covering over exposed surfaces including edges, to which it has attached.

Although not shown in Figure 2 (which is merely schematic), it is to be appreciated that, after introduction of the insulating material (or otherwise), the stack may be folded back on itself to create a z-fold arrangement having for example tens, possibly hundreds, and potentially thousands, of layers with each of the insulating plugs aligned. The laser cutting process performed by the second laser 122 may then be used to cut through the z-fold arrangement in a single cutting operation for each of the aligned sets of plugs.

After cutting the cells, electrical connectors can be provided along opposite sides of a cell, such that a first electrical connector on one side of the cell contacts the cathode layer(s) 104, but is prevented from contacting the other layers by the electrically insulating material. Similarly, a second electrical connector on an opposite side of the cell can be arranged in contact with the anode layer(s) 108, but is prevented from contacting the other layers by the insulating material. The insulating material may therefore reduce the risk of a short-circuit between the anode and cathode layers 104, 108, and the other layers in each cell. The first and second electrical connectors may, for example, comprise a metallic material that is applied to edges of the stack 100. The cells can therefore be joined in parallel in an efficient manner.

The foregoing description provides a general overview of an example of a stack 100 for an energy storage device, as well as an example of processing that may be applied to the stack 100, for example for the production of an energy storage device. The following description provides example methods and apparatuses for processing a stack (which may be the same as or similar to the stack 100 described with reference to Figure 1), which may provide for improvements in efficiency in the processing of the stack 200 and, hence, for the efficient production of an energy storage device such as a cell produced therefrom.

Referring to Figure 3, there is illustrated schematically a method of processing an energy storage device stack 200 according to an example.

In broad overview the method comprises, in step 201, obtaining a stack for an energy storage device, the stack comprising a first electrode layer, a second electrode layer, and an electrolyte layer between the first electrode layer and the second electrode layer. The method further comprises, in step 203, depositing a first material over an exposed portion, e.g. surface, of the first electrode layer and an exposed portion, e.g. surface, of the electrolyte layer. The method further comprises, in step 205, depositing a second material over the first material and to contact the second electrode layer, to provide an electrical connection from the second electrode layer, for connecting to a further such second electrode layer via the second material. The first material insulates the exposed portions, e.g. surfaces, of the first electrode layer and the electrolyte layer from the second material.

As explained in more detail hereafter, the method may allow for efficient and/or reliable connection of cells for an energy storage device in parallel, and hence, for example, for the efficient production of an energy storage device.

Referring now to Figures 4 and 5, there is illustrated schematically an energy storage device stack 200 (i.e. that may be obtained in accordance with examples of step 201 of the method described with reference to Figure 3) according to a first example.

The stack 200 may be the same as or similar to the stack 100 described with reference to Figure 1. In the example illustrated in Figure 4, the energy storage device stack 200 comprises a substrate layer 202, a cathode layer 204, an electrolyte layer 206, and an anode layer 208. In the example illustrated in Figure 4, the first electrode layer 204 is the cathode layer 204, and the second electrode layer 208 is the anode layer 208. The layers 202-208 of the stack 200 may be the same as or similar to the layers of the stack 100 described with reference to Figure 1. For example, the cathode layer 204 may comprise a cathode electrode and a cathode current collector (not shown in Figure 4) and the anode layer 208 may comprise an anode electrode and an anode current collector (not shown in Figure 4). In the example illustrated in Figure 4, the electrolyte layer 206 is between the cathode layer 204 and the anode layer 208, the cathode layer 204 is adjacent to the substrate layer 202, the electrolyte layer 206 is adjacent to the cathode layer 204, and the anode layer 208 is adjacent to the electrolyte layer 206. In this example, the substrate layer 202 is proximal to the cathode layer 204 relative to the anode layer 208. In this example, the substrate layer 202 may be or comprise a non-electrically conducting material such as polyethylene terephthalate (PET), although other materials may be used.

As illustrated in Figure 4, the energy storage device stack 200 has a cut 212 formed therein. The cut 212 may be formed in the stack 200 by laser ablation (not shown). The cut 212 is formed into a first side 200a of the stack 200, distal from the substrate layer 202. As illustrated in Figure 4, the cut 212 is formed through each of the anode layer 208, the electrolyte layer 206 and the cathode layer 204, but not the substrate layer 202. The laser ablation forming the cut may expose portions, such as surfaces (e.g. edges) 273, 274, 276, 278, of the substrate, cathode, electrolyte, and anode layers 202, 204, 206, 208.

In some examples, and as illustrated in Figures 4 and 5, the cut 212 is bounded only by the exposed portions 274, 276, 278 (which in this example may also be thought of as side portions of the cut 212) of the cathode, electrolyte, and anode 204, 206, 208 layers, and by an exposed portion, e.g. ledge 273, of the substrate layer 202 (which in this example may also be thought of as forming a base or a bottom surface of the cut 212). For example, the stack 200 may represent a segmented cell for an energy storage device, for example that has been segmented from a larger stack structure (not shown). In these examples, the portion of the stack 200 schematically illustrated in Figures 4 and 5 may be an end portion of a terminal of a cell. In other words, in these examples, the stack 200 may terminate (i.e. not continue) at the right-hand side of Figures 4 and 5. It is to be appreciated that, in some examples, the stacks of each of the examples described herein with reference to Figures 4 to 13 may be arranged in this way.

However, in other examples, the cut 212 may be in the form of a groove. In cases where the cut 212 is a groove, Figures 4 and 5 may be thought of as only showing the left-hand side of the groove. As used herein, the term “groove” may refer to a channel, slot or trench that may be continuous or non-continuous, and may in some examples be elongate, and which may extend only part way through the layers 202 – 208 of the stack 200. For example, the groove may be bounded on a first side by exposed portions 274, 276, 278 of the cathode, electrolyte, and anode layers 204, 206, 208, (which in this example may also be thought of as first side portions of the groove) on a second side by the exposed ledge 273 of the substrate layer 202 (which in this example may also be thought of as forming a base or a bottom surface of the groove), and on a third side by (similarly to the first side) further exposed portions, e.g. surfaces, (not shown) of cathode, electrolyte, and anode layers (nots shown) of the stack 200 (which in this example may also be thought of as second side portions of the groove). One or more such grooves 212 may be formed to segment the stack 200 into partial cell structures, but without (at this stage) completely separating those individual cell structures. It is to be appreciated that, in some examples, the stacks of each of the examples described herein with reference to Figures 4 to 13 may be arranged in this way.

In examples where the cut 212 is a groove, the (or each) groove may have a depth that extends into the stack 200 in a direction substantially perpendicular to the plane of the layers 202 – 208; a width substantially perpendicular to the depth (the width and depth of each groove are in the plane of the page in the sense of Figure 4), and a length that extends in a direction substantially parallel to the plane of the layers 202-208 and substantially perpendicular to the width (i.e. into the plane of the page in the sense of Figure 4). Where that are plural first grooves, they may be substantially parallel to one another in both the depth and length directions. It will therefore be appreciated that although a cut 212 will be referred to in the following, in each of the examples described herein, the cut 212 may take the form of a groove, and that in some examples there may be a plurality of such grooves formed in the stack 200.

In either case, as a result of the cut 212, as illustrated in Figure 4, the first electrode layer (in this example the cathode layer 204), the electrolyte layer 206, and the second electrode layer (in this example the anode layer 208) are recessed from the substrate layer 202 so that the substrate layer 202 provides a ledge portion, e.g. surface, 273, for example on which the first material 210 and/or the second material 214 may be at least partially supported.

It should be noted that Figure 4 (similarly to the other Figures) is a schematic diagram for illustrative purposes only. For example, the dimensions and relative spacings of the features illustrated in Figure 4 (e.g. the layers 202 – 208, the cut 212 or groove) are schematic only and merely serve to illustrate example structures and processes described herein.

As used herein, "laser ablation" may refer to the removal of material from the stack 200 using a laser-based process. This removal of material may comprise any one of multiple physical processes. For example the removal of material may comprise (without limitation) any one or combination of melting, melt-expulsion, vaporisation (or sublimation), photonic decomposition (single photon), photonic decomposition (multi-photon), mechanical shock, thermo-mechanical shock, other shock-based processes, surface plasma machining, and removal by evaporation (ablation).

Referring specifically to Figure 4, a first material 210 is being deposited over the exposed portion, e.g. surface, 274 of the first electrode layer (in this example the cathode layer 204) and an exposed portion, e.g. surface, 276 of the electrolyte layer 206 (in accordance with examples of step 203 of the method described with reference to Figure 3). The first material 210 is an electrically insulating material. An electrically insulating material may be considered to be electrically non-conductive and may therefore conduct a relatively a small amount of electric current when subjected to an electric field. Typically, electrically insulating material (sometimes referred to as an insulator) conducts less electric current than semiconducting materials or electrically conductive materials. However, a small amount of electric current may nevertheless flow through an electrically insulating material under the influence of an electric field, as even an insulator may include a small amount of charge carriers for carrying electric current. In examples herein, a material may be considered to be electrically insulating where it is sufficiently electrically insulating to perform the function of an insulator. This function may be performed for example where the material insulates sufficiently for short-circuits to be avoided.

In the example illustrated in Figure 4, the first (insulating) material 210 is deposited by inkjet material deposition. That is, in this example, deposition of the first material 210 uses inkjet technology for accurately depositing the first material 210 as droplets 224. In this example, the first material 210 is deposited in the form of ink by inkjet printing. The ink cures to form a solid material. However, it will be appreciated that in other examples, the first material may be deposited in a form other than ink, but may nonetheless be deposited using inkjet technology.

As mentioned, in this example, the first material is deposited by inkjet printing. That is, in this example, depositing the first material 210 comprises inkjet printing the first material 210. In this example, insulating ink is inkjet printed from an inkjet printing component, e.g. nozzle 220 of a deposition apparatus 230. The nozzle 220 prints droplets 224 of the insulating ink over the exposed portion 274 of the cathode layer 204 and the exposed portion 276 of the electrolyte layer 206.

In this example, the inkjet printing of the first material 210 is performed top-down. In other words, in this example, the droplets 224 travel from the nozzle 220 to the stack 200 with a velocity having a component that is in the same direction as the force on the droplets 224 due to gravity. Performing the ink-jet printing top-down may allow for accurate and efficient deposition of the first material 210.

In the example of Figure 4, the first (insulating) material 210 so printed is deposited onto and supported by the exposed portion or ledge 273 of the substrate layer 202. In this example, the printing nozzle 220 is angled with respect to the plane of the stack 200 so as to direct the droplets of ink 224 into a corner region of the cut 212 bounded by the exposed surfaces 274, 276 of the cathode and electrolyte layers 204, 206 and the ledge 273 provided by the substrate layer 202. This may allow for the first material 210, supported by the ledge 273, to build up against the exposed portions 274, 276 of the cathode and electrolyte layers 204, 206 so as to cover the exposed portions 274, 276 of the cathode and electrolyte layers 204, 206. In this example, the first material 210 is deposited so as not to cover the exposed portion 278 of the anode layer 208.

Once printed, the insulating ink 210 may be cured. For example, the insulating ink may be cured by evaporation of a carrier solvent of the insulating ink, which may occur at ambient temperatures, for example. As another example, the curing of the insulating ink may be facilitated by external curing means (not shown), for example by a heat source or an Ultra Violet (UV) light source (not shown), for example if curing of the insulating ink is facilitated thereby.

Referring to Figure 5, the first material 210 has been deposited as described with reference to Figure 4, and a second material 214 is being deposited over the first material 210 and to contact the second electrode layer (in this example the anode layer 208) to provide an electrical connection from the second electrode layer 208 (in accordance with examples of step 205 of the method described with reference to Figure 3).

The second material 214 is for electrically connecting the second electrode layer 208 to a further such second electrode layer (not shown in Figures 4 or 5) via the second material 214. The first material 210 insulates (i.e. electrically insulates) the exposed portions 276, 274 of the first electrode layer 204 and the electrolyte layer 206 from the second material 214. Therefore, electrical connection of the second electrode layer 208 may be provided to other such second electrode layers (not shown) of further such stack portions or cells (not shown) via the second material 214 to allow for electrical connection of the cells in parallel, but without the second material 214 causing a short between the first electrode layer 204 and the second electrode layer 208 of the stack 200.

The second material 214 is an electrically conductive material. For example, the second material 214 may have an electrical resistance lower, for example substantially lower, than the first material 210. In any case, the second material 214 has an electrical conductivity sufficient to provide an effective electrical connection from the second electrode layer (in this example the anode layer 208), for electrically connecting to a further such second electrode layer (not shown) via the second material 214.

In the example illustrated in Figure 5, the second (conducting) material 214 is deposited by inkjet material deposition, in this example inkjet printing of a conductive ink. That is, in this example, depositing the second material 214 comprises inkjet printing the second material 210. In this example, conducting ink is inkjet printed from an inkjet printing component, e.g. nozzle 220a of the deposition apparatus 230. The nozzle 220a prints droplets 226 of the conducting ink over the first material 210 and to contact the anode layer 208. In this example, the conducting ink 212 contacts and is printed over the exposed portion 278 of the anode layer 208. In this example, the second (conducting) material 210 so printed is deposited onto and supported by the exposed portion or ledge 273 of the substrate layer 202, as well as by the first material 210. In this example, the printing nozzle 220a is, again, angled with respect to the plane of the stack 200 so as to direct the droplets of conductive ink 226 over the first material 210 towards the corner region of the cut 212 bounded by the surfaces 274, 276 of the cathode and electrolyte layers 204, 206 (that were exposed but are now covered by the first material 210) and the ledge 273 provided by the substrate layer 202. This may allow for the second material 214, deposited onto and supported by the ledge 273 and/or by the first material 210, to build up against the first material 210 so as to cover the exposed portion 278 of the anode layer 208. Once printed, the conducting ink may be cured in an appropriate way. For example, the conducting ink may be cured in the same or similar way as described for the insulating ink.

The second material 214 is for connecting (i.e. electrically connecting) the second electrode layer 208 to a further such second electrode layer (not shown in Figures 4 or 5) via the second material 214. For example, the conductive material 214 may provide an electrical connection from the anode layer 208 to anode layers (not shown) of other cells, thereby to connect the anodes of the cells in parallel. The second material 214 may therefore form the positive terminal of an energy storage device comprising such cells. The first material 210 insulates (i.e. electrically insulates) the exposed portions 276, 274 of the cathode layer 204 and the electrolyte layer 206 from the second material 214, thereby preventing shorts between the anode layer 208 and the cathode layer 204. Therefore, electrical connection of the anode layers 208 of cells may be via the second material 214 to allow for electrical connection of the cells in parallel, but without the second material 214 causing a short between the anode layer 208 and the cathode layer 204. Connection of multiple cells may allow for the production of relatively large capacity energy storage devices. Connecting the cells in parallel may provide for an energy storage device that may have a relatively large discharge rate, which may be useful in some applications.

Depositing the first material 210 and/or the second material 214 by inkjet material deposition, such as inkjet printing may allow flexible, efficient, and/or reliable deposition. For example, inkjet printing may allow for more flexible, efficient, and/or reliable deposition as compared to, say, thermal spray coating in which material is sprayed onto the stack at high temperatures and in vacuum. For example, thermal spray coating may rely on an edge of the stack to be exposed and to be substantially perpendicular to the direction of the spray in order to be covered, or otherwise on wetting of the material onto the edge. This may limit the arrangement of the stack or the layers of the stack, and may be unreliable. However, the relatively high degree of spatial and directional control provided by inkjet printing may allow for small regions of the stack to be accurately and reliably targeted, which may improve the flexibility and reliability of the deposition, and hence improve the efficiency of cell production therefrom. As another example, the high temperatures associated with thermal spray coating may deform or damage the stack or layers thereof. However, deposition by inkjet printing may be conducted at relatively low, for example ambient temperatures, and hence may reduce or prevent damage of the stack, thereby improving the efficiency of cell production. As another example, the vacuum conditions and/or high temperatures associated with thermal spray coating may be energy intensive and hence may result in uneconomic or inefficient deposition. However, inkjet printing may be performed at relatively low (e.g. ambient) temperatures and/or pressures, and hence may allow for an economic and/or efficient deposition and hence cell production.

In the first example described with reference to Figures 4 and 5, the first electrode layer (over which the first material 210 is deposited) is the cathode layer 204 and the second electrode layer (that the second material 214 contacts) is the anode layer 208. It will be appreciated that this need not necessarily be the case, as described in more detail hereinafter with reference to Figures 6 and 7.

Referring now to Figures 6 and 7, there is illustrated schematically an energy storage device stack 200’ (i.e. that may be obtained in accordance with examples of step 201 of the method described with reference to Figure 3) according to a second example.

The stack 200' may be similar to the stack 200 described with reference to Figure 4. For brevity, features of the stack 200' of Figures 6 and 7 that are the same or similar to features of the stack 200 described with reference to Figures 4 and 5 will not be described in detail again. Like features are denoted by like reference signs.

In the example illustrated in Figure 6, similarly to as in the first example, the energy storage device stack 200' comprises a substrate layer 202, a cathode layer 204, and electrolyte layer 206, and an anode layer 208. However, in the example illustrated in Figure 6, the first electrode layer 208 is the anode layer 208, and the second electrode layer 204 is the cathode layer 204. Further, while in Figures 4 and 5 the cathode, electrolyte and anode layers 208, 206, 204 of the stack 200 are aligned with each other and recessed from the substrate layer 202, in the example of Figures 6 and 7 the anode and electrolyte layers 208, 206 are recessed from the cathode layer 204, thereby exposing a ledge, e.g. surface, 275 of the cathode layer 204. The ledge 275 of the cathode layer 204 is for supporting at least in part first material 210 and/or second material 214 deposited thereon. The cathode layer 204 is, similarly to as in Figures 4 and 5, recessed from the substrate layer 202 so that the substrate layer 202 provides a ledge, e.g. surface, 273, for supporting at least in part the second material 214.

Referring specifically to Figure 6, a first material 210 is being deposited over the exposed portion 278 of the first electrode layer (in this example the anode layer 208) and an exposed portion 276 of the electrolyte layer 206. The first material 210 is an electrically insulating material. The first material 210 may, again, be deposited by inkjet material deposition such as inkjet printing. That is, in his example, again, the nozzle 200 of the deposition apparatus 230 prints droplets 224 of insulating ink over the exposed portion 278 of the anode layer 208 and the exposed portion 276 of the electrolyte layer 206.

The insulating material 210 is supported by the exposed portion or ledge 275 of the cathode layer 204. The printing nozzle 220 again is arranged for top-down printing, and is angled with respect to the plane of the stack 200' so as to direct the droplets of ink 224 into a corner region of the cut 212' bounded by the exposed surfaces 278, 276 of the anode and electrolyte layers 208, 206 and the ledge 275 provided by the cathode layer 204. This may allow for the first material 210, supported by the ledge 275, to build up against the exposed portions 278, 276 of the anode and electrolyte layers 208, 206 so as to cover the exposed portions 278, 276 of the anode and electrolyte layers 208, 206.

In this example, the first material 210 is deposited so as not to cover the exposed portion 274 of the cathode layer 204. Once printed, the insulating ink may be cured, for example as described above with reference to Figures 4 and 5.

Referring to Figure 7, the first material 210 has been deposited as described with reference to Figure 6, and a second material 214 is being deposited over the first material 210 and to contact the second electrode layer (in this example the cathode layer 204). The second material 214 is an electrically conductive material. In the example illustrated in Figure 7, the second (conducting) material 214 is deposited by inkjet material deposition, in this example inkjet printing, i.e. by printing droplets of conducting ink 226 from the nozzle 220a of the deposition apparatus 230. The nozzle 220a prints droplets 226 of the conducting ink over the first material 210 and to contact the cathode layer 204. In this example, the conducting ink 212 contacts and is printed over the exposed portion 274 of the cathode layer 204. In this example, the second (conducting) material 210 so printed is supported by the portion or ledge 273 of the substrate layer 202, a part of the ledge 275 of the cathode layer 204, as well as the first material 210. The printing nozzle 220a may again be arranged for top-down printing and may be angled with respect to the plane of the stack 200 so as to direct the droplets of conductive ink 226 such that the second material 214, supported by the ledges 273, 274 and/or the first material 210, builds up so as to cover the exposed portion 274 of the cathode layer 274. Once printed, the conducting ink may be cured, for example as described with reference to Figures 4 and 5.

The second material 214 may provide an electrical connection from the cathode layer 204 to cathode layers (not shown) of other cells (not shown), thereby to connect the cathodes of the cells in parallel. In this example, the second material 214 may therefore form the negative terminal of an energy storage device comprising such cells. The first material 210 insulates (i.e. electrically insulates) the portions 276, 278 of the anode layer 208 and the electrolyte layer 206 (that were exposed but are now covered by the first material 210) from the second material 214, thereby preventing shorts between the anode layer 208 and the cathode layer 204. Therefore, electrical connection of the cathode layers 204 of cells may be via the second material 214 to allow for electrical connection of the cells in parallel, but without the second material 214 causing a short between the anode layer 208 and the cathode layer 204. Connecting cells together may allow for a relatively large capacity energy storage device to be produced. Connecting the cells in parallel may allow for relatively high discharge rates of the energy storage device, which may be useful in some applications. Depositing the first and/or second material by inkjet material deposition, such as inkjet printing may allow flexible, efficient, and/or reliable deposition as described with reference to Figures 4 and 5.

In the first and second examples of Figures 4 to 7, the second (conducting) material 214 is deposited by inkjet material deposition such as inkjet printing. It will be appreciated that this need not necessarily be the case, as described in more detail hereinafter with reference to Figures 8 and 9.

Referring to Figures 8 and 9, there is illustrated a stack 200’’ (i.e. that may be obtained in accordance with examples of step 201 of the method described with reference to Figure 3) according to a third example.

The stack 200’’ is similar to the stack 200 described above with reference to Figures 4 and 5, and hence for brevity features of the stack 200’’ of this third example that are the same as or similar to those of the stack 200 of the first example will not be described again. Like features are given like reference numerals. The stack 200’’ of Figure 8 differs from the stack 200 of Figure 4 in that in the stack 200’’ of Figure 8 the anode layer 208’’ is only partially formed, that is, the thickness of the anode layer 208’’ in Figure 8 is less than the thickness of the anode layer 208 of Figure 4. The partially formed anode layer 208’’ defines a first exposed portion, e.g. surface, 278’’ formed by the cut 212’’, and a second exposed portion, or ledge, 279. As with the stack 200 of Figure 4, in the stack 200’’ of Figure 8, the substrate layer 202 is proximal to the cathode layer 204 relative to the anode layer 208’’, that is, the anode layer 208’’ sits on the top of the stack 200’’ in the sense of Figure 8. In other words, the anode layer 208 is located towards the first side 200a of the stack 200’’, opposite to the second side 200b of the stack 200’’ towards which the substrate layer 202 is located. The second exposed portion or ledge 279 of the partially formed anode layer 208'' is therefore, in the sense of Figure 8, upwardly facing.

Referring specifically to Figure 8, a first material 210 is being deposited over the exposed portion 274 of the first electrode layer (in this example the cathode layer 204) and an exposed portion 276 of the electrolyte layer 206. This process may be the same as described above with reference to Figure 4. As illustrated, the first material 210 is deposited so as not to cover the first exposed portion 278'' of the partially formed anode layer 208''. However, in this example, the first material 210 may be deposited so as to cover the first exposed portion 278'' since, as described in more detail with reference to Figure 9, in this example, the second material 214'' need not necessarily contact that first exposed portion 278'' of the anode layer 208'' and may alternatively or additionally contact the second exposed surface e.g. ledge 279 of the anode layer 208''.

Referring to Figure 9, the first material 210 has been deposited as described with reference to Figure 8, and a second material 214'' is being deposited over the first material 210 and to contact the second electrode layer (in this example, the partially formed anode layer 208''). The second material 214'' is an electrically conductive material. In this example, the second material 214'' is or comprises anode material. For example, the second material 214'' may be or comprise the same material as the anode layer 208''. In this example, the second (anode) material 214'' is deposited over the partially formed anode layer 208''. That is, in this example, the second (anode) material 214'' is deposited over the second exposed surface, or ledge, 279 of the partially formed anode layer 208'', thereby to complete the anode layer 208. That is, after the deposition of the second (anode) material 214, the anode layer 208 may be fully, rather than partially, formed. The second (anode) material 214'' is deposited over the first material 210, and over the ledge 273 of the substrate layer 202. The second (anode) material 214'' may be deposited in the same or a similar way to the way in which the partially formed anode layer 208'' was deposited. For example, the second (anode) material 214'' may be deposited by vapor deposition, for example physical vapor deposition, for example flood deposition, although other deposition methods may be used. For example, a deposition device 220b of the deposition apparatus 230 may be arranged to deposit 226b second (anode) material 214’’ over substantially the entire first side 200a of the stack 200’’.

The second (anode) material 214’’ is for connecting (i.e. electrically connecting) to a further such anode layer (not shown in Figures 8 or 9) via the second material 214’’. For example, the conductive material 214’’ may provide an electrical connection from the anode layer 208 to anode layers (not shown) of other cells, thereby to connect the anodes of the cells in parallel. In this example, the second material 214 may therefore form the positive terminal of an energy storage device comprising such cells. The first material 210 insulates (i.e. electrically insulates) the exposed portions 274, 276 of the cathode layer 204 and the electrolyte layer 206 from the second (anode) material 214’’, thereby preventing shorts between the anode layer 208 and the cathode layer 204. Therefore, electrical connection of the anode layers 208 of cells may be via the second material 214 to allow for electrical connection of the cells in parallel, but without the second material 214 causing a short between the anode layer 208 and the cathode layer 204. Depositing anode material as the second material 214’’ may allow for efficient deposition of the second material 214’’, and hence efficient cell production. For example, depositing anode material may allow for the anode layer 208’’ of the obtained stack 200’’ to be only partially formed, and for the deposited anode material to complete the anode layer 208’’. This may reduce the total amount of conductive and/or anode material used in order to produce a cell from the stack 200’’. As another example, the anode material may be relatively inexpensive. For example, the anode material may be inexpensive as compared to conductive inks and/or compared to cathode material. Therefore, providing an electrical connection for the anode layer 208’’ to other such anode layers of further cells using anode material may allow for the cost of the cell production to be reduced, and hence may allow for more efficient cell production. As another example, the deposition of anode material, for example by vapor deposition, for example physical vapor deposition, for example flood deposition, may be relatively fast and/or inexpensive, for example, as compared to inkjet printing. As another example, using the same method and/or means to deposit the partially formed anode layer 208’’ as to deposit the second (anode) material 214’’ may be efficient, for example as compared to providing separate methods and/or means for each function.

It will be appreciated that, in some examples, the stack 200' shown in Figures 6 and 7, in which the second material provides an electrical connection for the cathode layer 204, and the stack 200 shown in Figures 4 and 5 or the stack 200'' shown in Figures 8 and 9, in which the second material provides an electrical connection for the anode layer 208, may be different portions of the same stack, i.e. different terminals of the same cell (not shown). For example, the electrical connection 212 for the cathode layer 204 shown in Figures 6 and 7 may be provided on a first side of a cell (not shown) to provide the negative terminal of a given cell, and the electrical connection 212 for the anode 208 shown in Figures 4 and 5, or Figures 8 or 9, may be provided on an opposite side of the given cell (not shown) to provide the positive terminal of the given cell. This may allow for the efficiency and/or reliability improvements described hereinbefore for the electrical connections of the cathode layer 204 and the anode layer 208 to provided for the same cell, which may therefore improve further the efficiency or reliability of an energy storage device provided therefrom.

In the first to third examples of Figures 4 to 9, the stack 200, 200'' has only one each of the anode layer 208, the electrolyte layer 206 and the cathode layer 204, supported on the substrate layer 202. It will be appreciated that this need not necessarily be the case, as described in more detail hereinafter with reference to Figures 10 to 13.

Referring to Figure 10, there is illustrated a stack 200''' (that may be obtained in accordance with examples of step 201 of the method described with reference to Figure 3) according to a fourth example. The stack 200''' may be similar to the stack 200 described with reference to Figure 4, and so, for brevity, features that are the same will not be described in detail again. Like features are given like reference numerals.

The stack 200''' of Figure 10 differs from the stack 200 of Figure 4 in that the stack 200''' of Figure 10 comprises a further second electrode layer 208a (in this example a further anode layer 208a), and a further electrolyte layer 206a between the further second electrode layer 208a and the first electrode layer (in this example the cathode layer 204). More specifically, in this example, the stack 200''' comprises not only the substrate layer 202, the cathode layer 204, the electrolyte layer 206 and the anode layer 208, but also a first further electrolyte layer 206a (deposited over the anode layer 208), a further cathode layer 204a (deposited over the first further electrolyte layer 206a), a second further electrolyte layer 206b (deposited over the further cathode layer

204a), and a further anode layer 208a (deposited over the second further electrolyte layer 206b). The stack 200''' of this fourth example may be referred to as "multi-stack" or a "multi-cell" stack in that the stack 200''' has formed on one substrate layer 202 layers that may constitute multiple cells. For example, the cathode layer 204, the electrolyte layer 206 and the anode layer 208 may constitute a first cell, the anode layer 208 the first further electrolyte layer 206a, and the further cathode layer 204a may constitute a second cell, and the further cathode layer 204a, the second further electrolyte layer 206b, and the further anode layer 208a may constitute a third cell of the multi-cell stack 200'''. That is, in these examples, the anode layer 208 may act as an anode layer for both the first and second cells, and the further cathode layer 204a may act as a cathode layer for both the second and third cells. This may be an efficient arrangement as it may allow for the amount of anode and/or cathode material required to form multiple cells to be reduced.

As with the stack 200 of Figure 4, the cut 212''' in the stack 200''' of Figure 10 is such that the cathode layer 204, the electrolyte layer 206 and the anode layer 208 are aligned and recessed from the substrate layer 202 such that the substrate layer provides the ledge 273. However, in the stack 200'' of Figure 10, the cut 212'' or groove is such that first further electrolyte layer 206a, the further cathode layer 204a, the second further electrolyte layer 206b, and the further anode layer 208a are aligned and recessed from the anode layer 208 so that the anode layer provides the ledge 279. In this example, the cut 212''' may be formed from plural cutting steps, for example by laser ablation using different and/or offset laser beams. For example, the cut 212''' may be formed by firstly cutting the stack 200''' to expose the portions 276a, 274a, 276b, 278a of the first further electrolyte layer 206a, the further cathode layer 204a, the second further electrolyte layer 206b and the further anode layer 208, and the ledge 279 of the anode layer 208; and secondly cutting the stack 200''' to expose the portions 274, 276, 278 of the cathode layer 204, the electrolyte layer 206 and the anode layer, and the ledge 273 of the substrate layer 202.

As with the stack 200 of Figure 4, in the example of Figure 10, the first material 210 is deposited over the exposed edges 274, 276 of the cathode layer 204 and the electrolyte layer 206, and the first material 210 is supported by the ledge 273 of the substrate layer 202. However, in the stack 200'' of Figure 10, first material 210 is also deposited over an exposed portions 276a, 276b of the further electrolyte layers 206a, 206b. More specifically, as illustrated in Figure 10, the first material 210 is deposited over the exposed portions 276a, 274a, 276b of the first further electrolyte layer 206a, the further cathode layer 204a, and the second further electrolyte layer 206b. The first material 210 is supported by the ledge 279 provided by the anode layer 208. As a result, the exposed portions 278, 278a of the anode layer 208 and the further anode layer 208a remain exposed. The first material may be deposited, for example, by inkjet printing, for example as described with reference to Figures 4 and 5.

Referring to Figure 11, as with the stack 200 of Figure 5, second material 214 is deposited over the first material 210 and to contact the second electrode layer (in this example the anode layer 208). However, in the stack 200''' of Figure 11, the second material 214 is deposited to also contact the further second electrode layer (in this example the further anode layer 208). As a result the anode layer 208 and the further anode layer 208 are connected (electrically connected) via the second material 214. In this example, the second material 214 is at least partly supported by the ledge 279 of the anode layer 208 and the ledge 273 of the substrate layer 202. The first material 210 electrically insulates the exposed portions 274, 276, 276a, 274a, 276b of the cathode layer 204, the electrolyte layer 206, the first further electrolyte layer 206a, the further cathode layer 204a, and the second further electrolyte layer 206b from the second material 214.

The second material 214 may be deposited by inkjet material deposition, such as inkjet printing as described with reference to Figures 4 or 5. Alternatively, the further anode layer 208a may be partially formed, and the second material 214 may be or comprise anode material which may be deposited using e.g. flood deposition, for example as described with reference to Figures 8 and 9.

The second material 214 provides an electrical connection from the anode layer 208 of the first and second cells of the multi-cell stack 200''' to the further anode layer 208a of the third cell of the multi-cell stack, thereby to connect the first to third cells in parallel. The second material 214 may therefore form the positive terminal of an energy storage device comprising such cells. The first material 210 insulates (i.e. electrically insulates) the exposed portions 274, 276, 276a, 274a, 276b of the cathode layer 204, the electrolyte layer 206, the first further electrolyte layer 206a, the further cathode layer

204a, and the second further electrolyte layer 206b from the second material 214, thereby preventing shorts between the anode layers 208, 208a and the cathode layers 204, 204a. Therefore, electrical connection of the anode layers 208, 208a of the cells may be via the second material 214 to allow for electrical connection of the cells in parallel, but without the second material 214 causing a short between the anode layers 208, 208a and the cathode layers 204, 204a.

Providing electrical connections between cells in a multi-cell stack 200''' such as in Figures 10 and 11 may provide for efficient cell production. For example, the multi-cell stack 200''' may reduce the amount of substrate layer 202 per cell, and hence may reduce cost associated with providing substrate layer 202. As another example, the second material 214 connecting multiple cells may be deposited in a single deposition, which may reduce time and hence cost, for example as compared to electrically connecting cells one by one.

In the fourth example of Figures 10 and 11, the anode layer 108 and the further anode layer 208a are electrically connected by the second material 214. It will be appreciated that this need not necessarily be the case, as described in more detail hereinafter with reference to Figures 12 and 13.

Referring to Figure 12, there is illustrated a stack 200'''' (that may be obtained in accordance with examples of step 201 of the method described with reference to Figure 3) according to a fifth example. The stack 200'''' may be similar to the stack 200' described with reference to Figure 6. For brevity, features that are the same will not be described in detail again. Like features are given like reference numerals. The stack 200'''' of Figure 12 differs from the stack 200' of Figure 6 in that the stack 200'''' of Figure 12 comprises a further second electrode layer 204a (in this example a further cathode layer 204a), and a further electrolyte layer 206a between the further second electrode layer 204a and the first electrode layer (in this example the anode layer 208). More specifically, in this example, the stack 200'''' comprises not only the substrate layer 202, the cathode layer 204, the electrolyte layer 206 and the anode layer 208, but also a first further electrolyte layer 206a (deposited over the anode layer 208), a further cathode layer 204a (deposited over the first further electrolyte layer 206a), a second further electrolyte layer 206b (deposited over the further cathode layer 204a), and a further anode layer 208a (deposited over the second further electrolyte layer 206b).

Such a stack 200'''' may be referred to as “multi-stack” or a “multi-cell” stack 200'''', in that the stack 200'''' has formed on one substrate 202 layers that may constitute multiple cells. For example, the cathode layer 204, the electrolyte layer 206 and the anode layer 208 may constitute a first cell, the anode layer 208 the first further electrolyte layer 206a, and the further cathode layer 204a may constitute a second cell, and the further cathode layer 204a, the second further electrolyte layer 206b, and the further anode layer 208a may constitute a third cell, of the multi-cell stack 200''''.

As with the cut 212' of the stack 200' of Figure 6, the cut 212'''' in the stack 200'''' of Figure 12 is such that the cathode layer 204 is recessed from the substrate layer 202 so that the substrate layer 202 provides the ledge 273, and the electrolyte layer 206 and the anode layer 208 are aligned and recessed from the cathode layer 204 such that the cathode layer 204 provides the ledge 275. However, in the stack 200'''' of Figure 12, the cut 212'''' or groove is such that first further electrolyte layer 206a and the further cathode layer 204a are aligned with the electrolyte layer 206 and the anode layer 208, and the second further electrolyte layer 206b and the further anode layer 208a are aligned and recessed from the further cathode layer 204a so that the further cathode layer 204a provides a further ledge 275a. The cut 212'''' may be formed by plural cutting steps.

As with the stack 200' of Figure 6, as illustrated in Figure 12, the first material 210 is deposited over the exposed edges 276, 278 of the electrolyte layer 206 and the anode layer 208, and the first material 210 is supported by the ledge 275 of the cathode layer 204. However, in the stack 200'''' of Figure 12, first material 210 is also deposited over exposed portions 276a, 276b of the further electrolyte layers 206a, 206b. More specifically, as illustrated in Figure 12, the first material 210 is deposited over the exposed portions 276a, 278b, 278a of the first further electrolyte layer 206a, the second further electrolyte layer 206b and the further anode layer 208. The portion of the first material 210 that covers the exposed portions 278b, 278a of the second further electrolyte layer 206b and the further anode layer 208 is supported by the ledge 275a provided by the first further cathode layer 204a. As a result, the exposed portions 274, 274a of the cathode layer 204 and the further cathode layer 204a remain exposed. The first material 210 may be deposited, for example, by inkjet material deposition such as inkjet printing, for example as described with reference to Figures 6 and 7.

Referring to Figure 13, as with the stack 200’’ of Figure 7, as illustrated in Figure 13, second material 214 is deposited over the first material 210 and to contact the second electrode layer (in this example the cathode layer 204). However, in the stack 200’’’’ of Figure 13, the second material 214 is deposited to also contact the further second electrode layer (in this example the further cathode layer 204a). As a result the cathode layer 204 and the further cathode layer 204a are connected (electrically connected) via the second material 214. In this example, the second material 214 is at least partly supported by the ledge 275a of the further cathode layer 204a, the ledge 275 of the cathode layer 204, and the ledge 273 of the substrate layer 202. The first material 210 electrically insulates the exposed portions 276, 278, 276a, 276b, 278a of the electrolyte layer 206, the anode layer 208, the first further electrolyte layer 206a, the second further electrolyte layer 206b and the further anode layer 208a from the second material 214. The second material 214 may be deposited by inkjet printing as described with reference to Figures 6 or 7.

The second material 214 provides an electrical connection from the cathode layer 204 of the first cell of the multi-cell stack 200’’’’ to the further cathode layer 204a of the second and third cell of the multi-cell stack, thereby to connect the first to third cells in parallel. The second material 214 may therefore form the negative terminal of an energy storage device comprising such cells. The first material 210 prevents shorts between the anode layers 208, 208a and the cathode layers 204, 204a. Therefore, electrical connection of the cathode layers 204, 204a of the cells may be via the second material 214 to allow for electrical connection of the cells in parallel, but without the second material 214 causing a short between the anode layers 208, 208a and the cathode layers 204, 204a.

Providing electrical connections between cells in a multi-stack or multi-cell stack 200’’’ such as in Figures 12 and 13 may provide for efficient cell production, for example similarly to as described above with reference to Figures 10 and 11.

It will be appreciated that although only three cells are provided in the multi-cell stacks 200’’’, 200’’’’ of Figures 10 to 13, in other examples, there may be more or less cells. For example, the multi-cell stack 200’’’, 200’’’’ may comprise a plurality of cells, where the stack 200’’’, 200’’’ comprises at least the first electrode layer 204, 208, an electrolyte layer 206, a second electrode layer 204, 208, a further electrolyte layer 206a, 206b, and a further second electrode layer 204a, 208a.

It will be appreciated that, in some examples, the stack 200'''' shown in Figures 12 and 13 in which the second material provides an electrical connection for the cathode layers 204, 204a, and the stack 200''' shown in Figures 10 and 11 in which the second material provides an electrical connection for the anode layers 208, 208a, may be different portions of the same multi-cell stack, i.e. provide different terminals of same cells (not shown). For example, the electrical connection 212 for the cathode layers 204, 204a shown in Figures 12 and 13 may be provided on a first side of a cells (not shown) to provide the negative terminal for the cells, and the electrical connection 212 for the anode layers 208, 208a shown in Figures 10 and 11 may be provided on an opposite side of the cells (not shown) to provide the positive terminal of the cells.

It will be appreciated that although in each of the above examples the first material 210 is described as being deposited by inkjet material deposition such as inkjet printing, this need not necessarily be the case, and in some examples the first material 210 and/or the second material 214 may be deposited by methods other than inkjet material deposition.

It will be appreciated that a product of each of the examples described with reference to Figures 3 to 13 may be an intermediate product of an energy storage device production process, and that in some examples further processing may be performed on the stacks 200-200''' in order to produce the energy storage device.

In the various examples described above, this intermediate product takes the form of a stack 200-200'''' for an energy storage device, the stack 200-200'''' comprising a first electrode layer 204/208, a second electrode layer 204/208, and an electrolyte layer 206 between the first electrode layer 204/208 and the second electrode layer 204/208. The stack 200-200'''comprises a first material 210 over a portion 274/278 of the first electrode layer 204/208 (i.e. the portion 274/278 that would be exposed but for the first material 210 covering it) and a portion 276 of the electrolyte layer 206 (i.e. the portion 276 that would be exposed but for the first material 210 covering it). The stack comprises a second material 214 over the first material 210 and contacting the second electrode layer 204/208 to provide an electrical connection from the second electrode layer 204/208, for connecting to a further such second electrode layer 204a/208a via the second material 214. The first material 210 insulates the exposed portions 274/278, 276 of the first electrode layer 204/208 and the electrolyte layer 206 from the second material 214.

The above examples are to be understood as illustrative examples of the invention. It is to be understood that any feature described in relation to any one example may be used alone, or in combination with other features described, and may also be used in combination with one or more features of any other of the examples, or any combination of any other of the examples. Furthermore, equivalents and modifications not described above may also be employed without departing from the scope of the invention, which is defined in the accompanying claims.

CLAIMS

1. A method comprising:

obtaining a stack for an energy storage device, the stack comprising a first electrode layer, a second electrode layer, and an electrolyte layer between the first electrode layer and the second electrode layer;

depositing a first material over an exposed portion of the first electrode layer and an exposed portion of the electrolyte layer; and

depositing a second material over the first material and to contact the second electrode layer, to provide an electrical connection from the second electrode layer, for connecting to a further such second electrode layer via the second material,

whereby the first material insulates the exposed portions of the first electrode layer and the electrolyte layer from the second material.

2. The method according to claim 1, wherein depositing the first material comprises inkjet material deposition of the first material.

3. The method according to claim 1 or claim 2, wherein the stack comprises a substrate proximal to one of the first electrode layer and the second electrode layer, wherein the other of the first electrode layer and the second electrode layer is an anode layer.

4. The method according to claim 3, wherein the anode layer comprises anode material, and wherein the second material is the same as the anode material.

5. The method according to claim 3 or claim 4, wherein depositing the second material comprises depositing the second material over the anode layer.

6. The method according to any one of claim 1 to claim 3, wherein depositing the second material comprises inkjet material deposition of the second material.

7. The method according to any one of claims 1 to 6, wherein the first electrode layer, the electrolyte layer, and the second electrode layer are recessed from the substrate so that the substrate provides a ledge portion on which the first material and/or the second material is/are at least partially supported.

8. The method according to any one of claims 1 to 7, wherein the first electrode layer and the electrolyte layer are recessed from the second electrode layer so that the second electrode layer provides a ledge portion on which the first material and/or the second material is/are at least partially supported.

9. The method according to any one of claim 1 to claim 8, wherein the further such second electrode layer is of a further such stack.

10. The method according to any one of claims 1 to claim 8, wherein the stack comprises a said further second electrode layer, and a further electrolyte layer between the further second electrode layer electrode layer and the first electrode layer, wherein depositing the first material further comprises depositing the first material over an exposed portion of the further electrolyte layer, and wherein depositing the second material further comprises depositing the second material to contact the further second electrode layer, thereby to connect the second electrode layer and the further second electrode layer via the second material, whereby the first material further insulates the exposed portion of the further electrolyte layer from the second material.

11. The method according to claim 10, wherein the electrolyte layer, the first electrode layer, the further electrolyte layer, and the further second electrode layer are recessed from the second electrode layer such that the second electrode layer provides a ledge on which the first material and/or the second material is/are supported.

12. The method according to any one of claim 1 to claim 11, wherein the method comprises laser ablating the stack, and wherein one or more of the exposed portions are exposed by the laser ablating of the stack.

13. A stack for an energy storage device, the stack comprising a first electrode layer, a second electrode layer, and an electrolyte layer between the first electrode layer and the second electrode layer, the stack comprising a first material over a portion of the first electrode layer and a portion of the electrolyte layer; and a second material over the first material and contacting the second electrode layer to provide an electrical connection from the second electrode layer, for connecting to a further such second electrode layer via the second material, wherein the first material insulates the portions of the first electrode layer and the electrolyte layer from the second material.

14. An energy storage device formed according to the method of any one of claims 1 to 12.

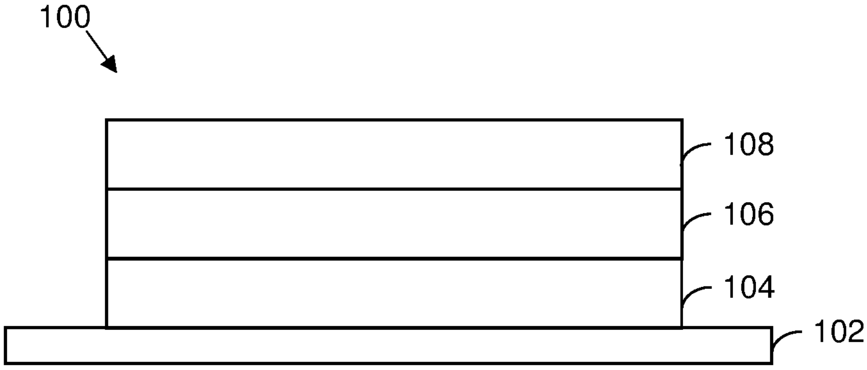


FIG 1

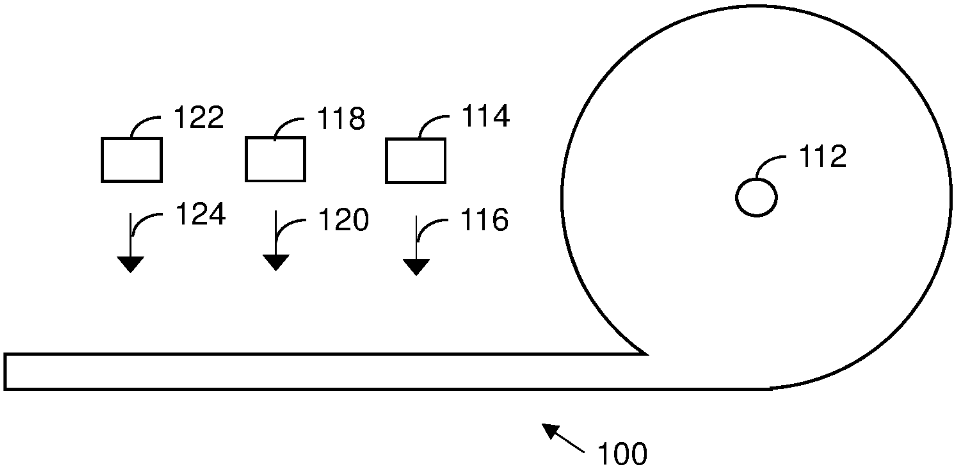
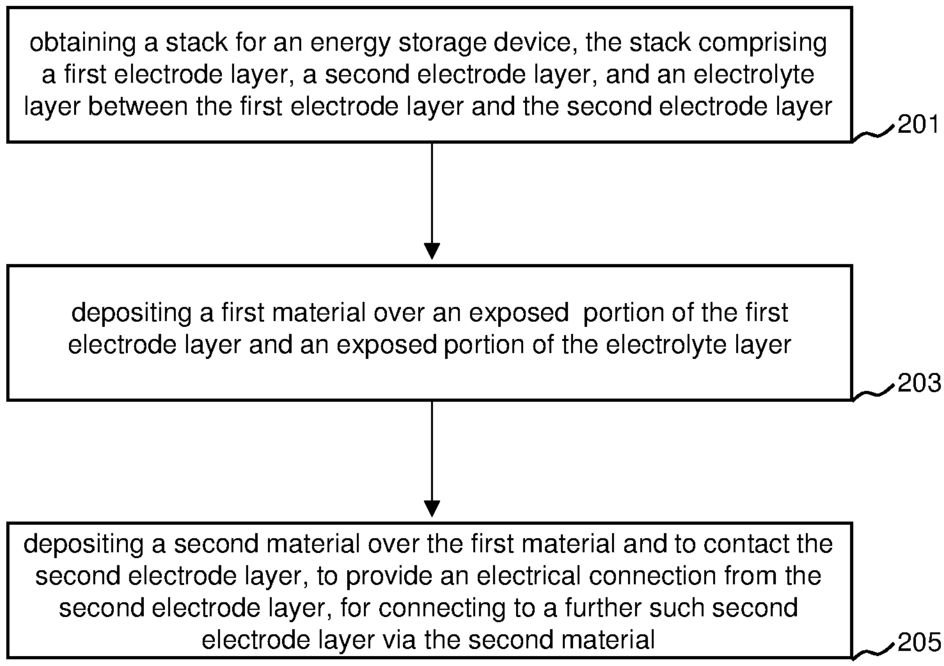


FIG 2


obtaining a stack for an energy storage device, the stack comprising a first electrode layer, a second electrode layer, and an electrolyte layer between the first electrode layer and the second electrode layer
201
depositing a first material over an exposed portion of the first electrode layer and an exposed portion of the electrolyte layer
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depositing a second material over the first material and to contact the second electrode layer, to provide an electrical connection from the second electrode layer, for connecting to a further such second electrode layer via the second material
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FIG 3

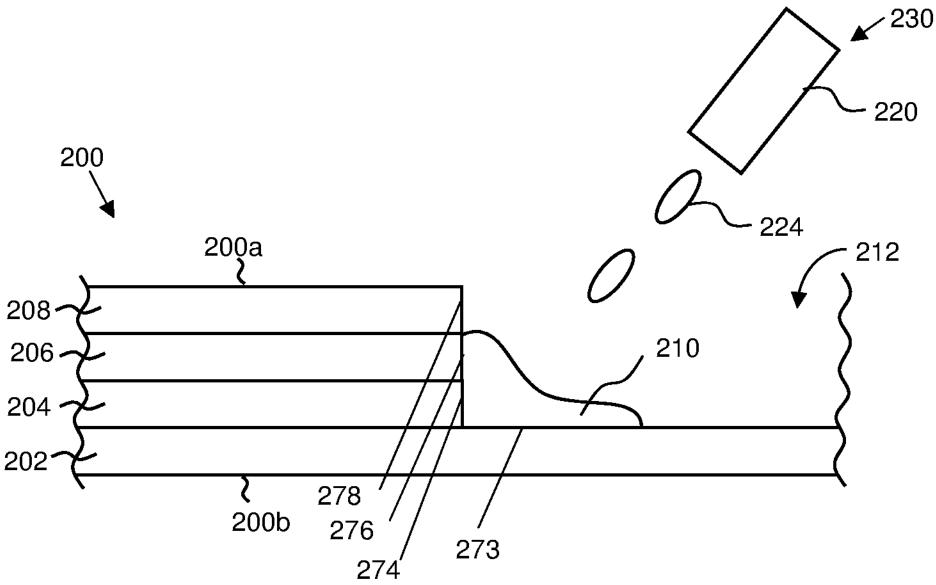
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FIG 4

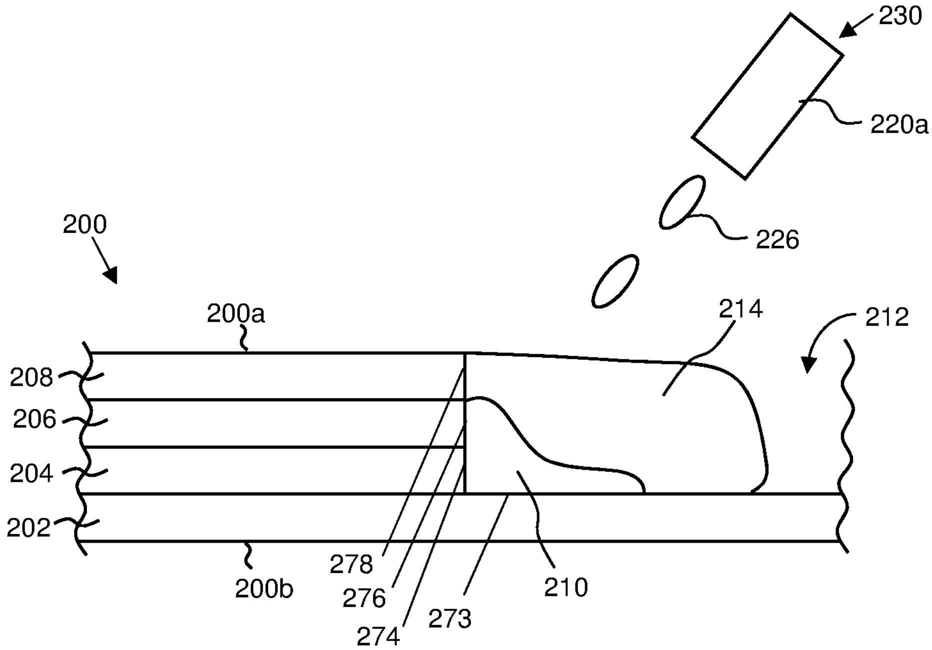
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FIG 5

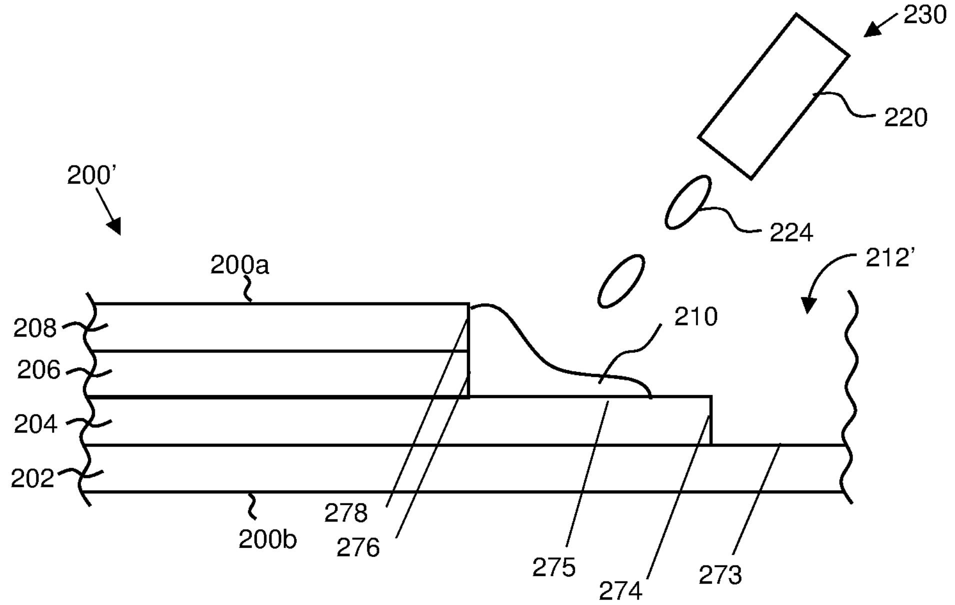
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FIG 6

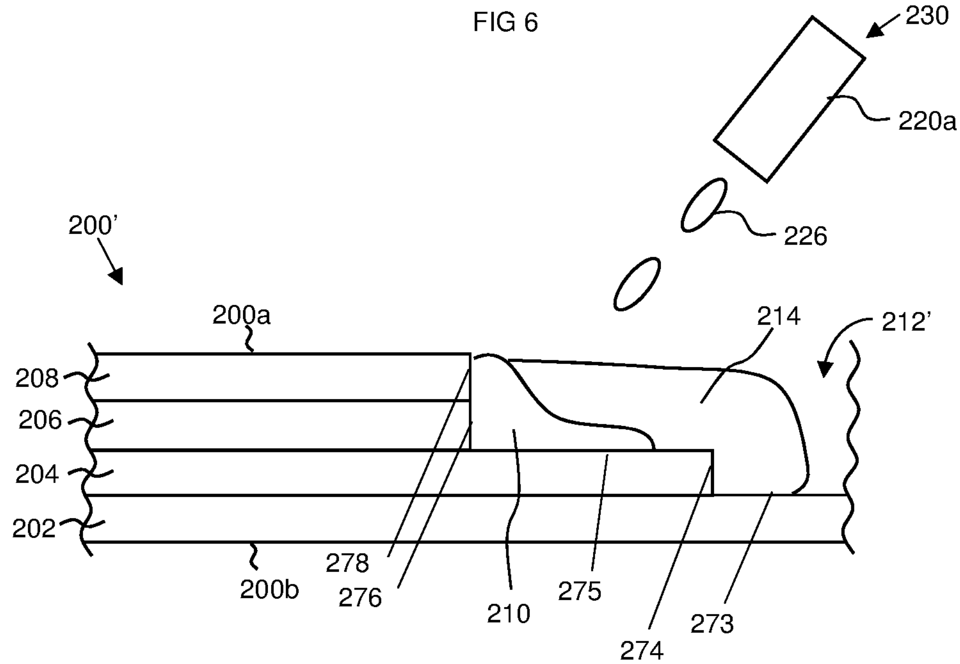
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FIG 7

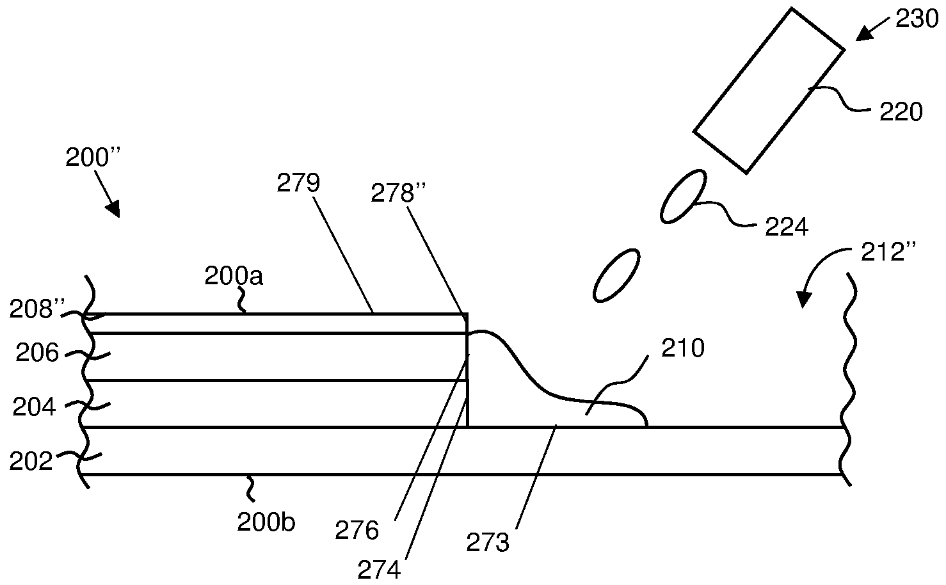
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FIG 8

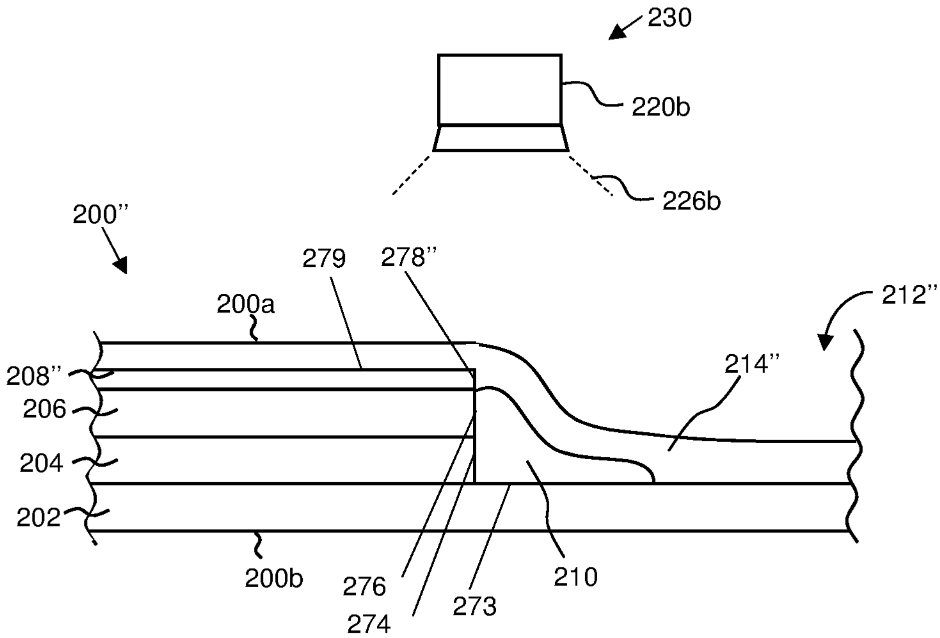
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FIG 9

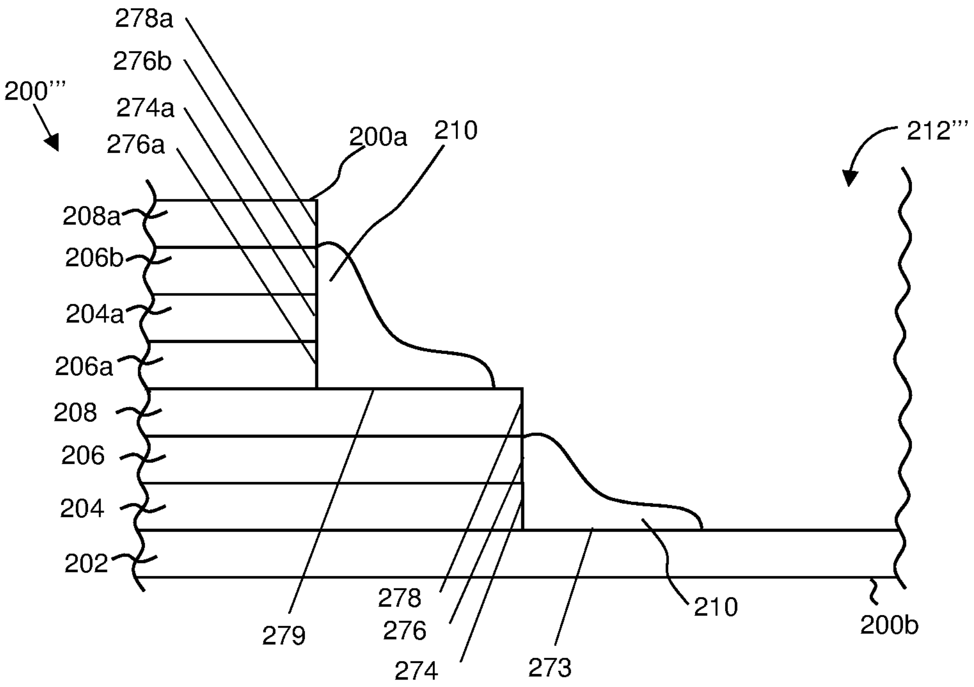
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FIG 10

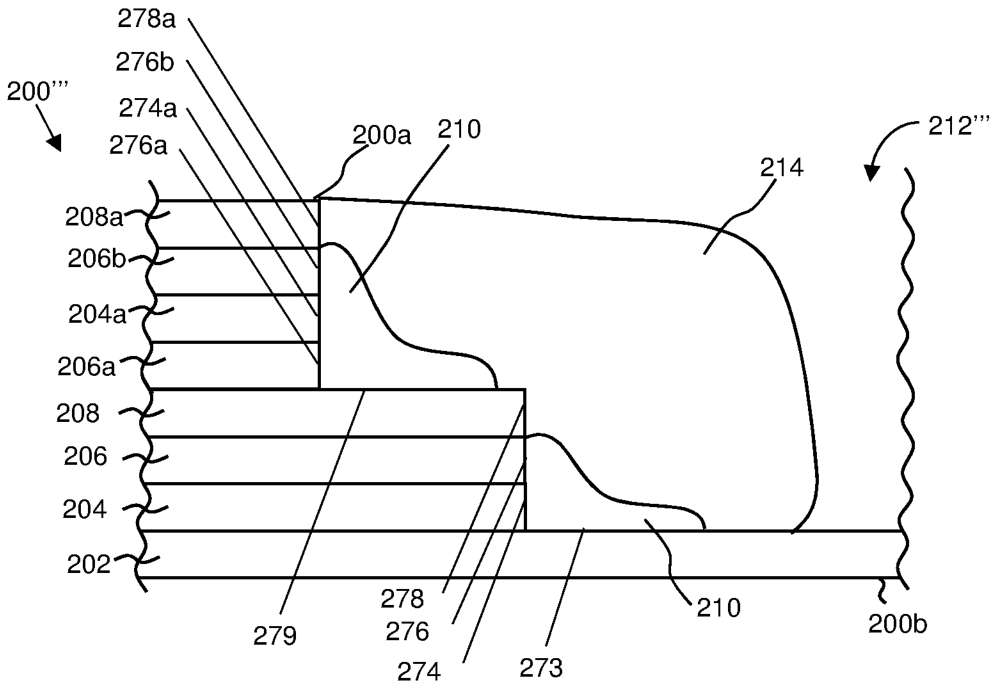
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FIG 11

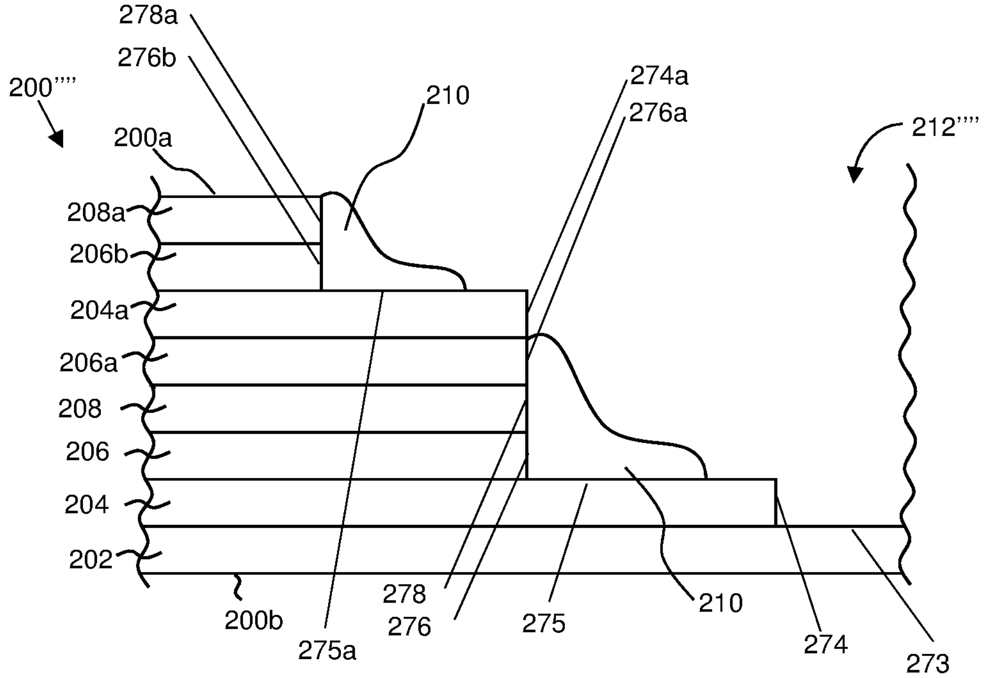

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FIG 12

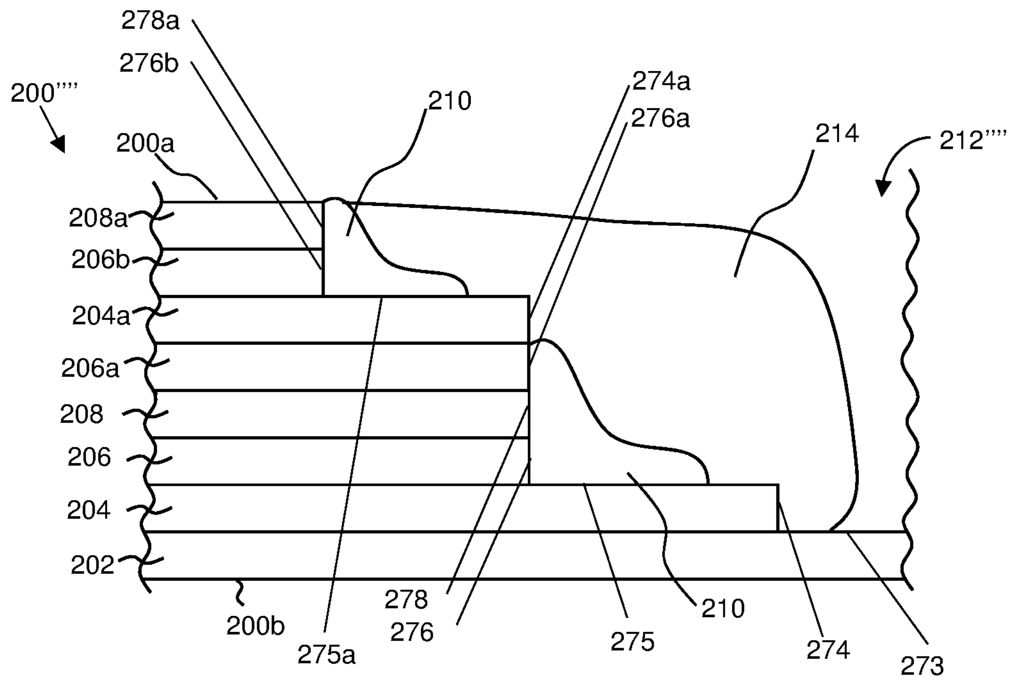

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FIG 13

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2019/052042

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01M4/04 H01M4/139 H01M6/40 H01M10/0562 H01M10/0585
H01M10/058
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X	US 2007/139001 A1 (HAHN ROBERT [DE]) 21 June 2007 (2007-06-21) paragraphs [0041] - [0046], [0054] - [0056], [0058]; figures 1a-8a, 9a-9b, 11 -----	1-3,5-14
X	EP 2 948 995 A1 (APPLEJACK 199 L P [US]) 2 December 2015 (2015-12-02) column 3, line 47 - column 4, line 34; figures 1A-1D paragraph [0033] column 8, lines 36-39 -----	1-7,9, 12-14
A	US 2004/126655 A1 (HISAMITSU YASUNARI [JP] ET AL) 1 July 2004 (2004-07-01) paragraphs [0039] - [0041] -----	1-14

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 August 2019	19/09/2019

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Monti, Adriano

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2019/052042

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