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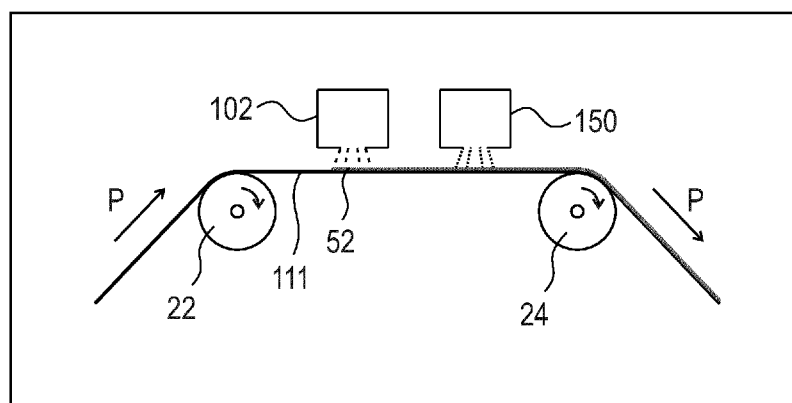


Fig. 1

(57) Abstract: A processing system for forming a component of an electrochemical energy storage device is provided. The processing system includes a deposition module (102) configured for depositing a ceramic layer (52) over a flexible substrate (111), and an oxidation module (150) configured to subject the ceramic layer (52) to an oxidizing atmosphere at an elevated temperature.

METHOD AND PROCESSING SYSTEM FOR FORMING A COMPONENT
OF AN ELECTROCHEMICAL ENERGY STORAGE DEVICE AND
OXIDATION CHAMBER

5

TECHNICAL FIELD

[0001] Embodiments of the present disclosure relate to methods and processing systems for forming a component of an electrochemical energy storage device and oxidation
10 chambers. Embodiments of the present disclosure particularly relate to a method and processing systems for forming a cathode, anode, electrolyte or separator of a lithium or Li-ion battery and oxidation chambers for post processing a cathode, anode, electrolyte or separator of a lithium or Li-ion battery.

15 BACKGROUND

[0002] An electrical separator may, for instance, be described as a separator used in batteries and other arrangements in which electrodes are to be separated from each other while maintaining ion conductivity.

[0003] Conventionally, a separator includes a thin, porous, electrically insulating
20 substance with high ion porosity, good mechanical strength and long-term stability with respect to the chemicals and solvents used in the system, for example, in the electrolyte of the battery. In batteries, the separator does normally completely electrically insulate the cathode from the anode. In addition, the separator is normally permanently elastic and follow the movements in the system which stem not merely from external loads but also from the “breathing” of the
25 electrodes as the ions are incorporated and discharged.

[0004] In general, the separator is crucial in determining the lifetime and the safety of the system in which the separator is used. For instance, the development of rechargeable batteries is being influenced to a significant degree by the development of suitable separator materials.

[0005] Specifically, separators for use in high-energy batteries or high-performance batteries may be very thin in order to ensure a low specific space condition and in order to minimize the internal resistance, have a high porosity in order to ensure low internal resistances, and are light in order to achieve a low specific weight of the battery system.

5 [0006] The separators typically include a ceramic layer being porous to ions of the battery. For the case of lithium batteries, the ceramic layer can be porous for lithium ions (Li-ions). However, the ceramic layers may not be fully porous. For instance, the ceramic layer may include metal atoms that are not fully bound and may react with Li-ions during charge/discharge of the Li-ion battery. Hence, the battery performance may be deteriorated.

10 [0007] In view of the above, embodiments described herein aim to provide methods and systems for forming components of an electrochemical energy storage device that may overcome at least some of the problems in the art are beneficial. The present disclosure aims to provide methods and systems for forming components of an electrochemical energy storage device that may increase charge transport (discharge/charge rates) voltage and cycle life span
15 of the electrochemical energy storage device.

SUMMARY

[0008] In light of the above, a method and a processing system for forming components of an electrochemical energy storage device and an oxidation chamber configured
20 to oxidize a ceramic layer of a component of an electrochemical energy storage device according to the independent claims are provided. Further aspects, advantages, and features of the present application are apparent from the dependent claims, the description, and the accompanying drawings.

[0009] According to an aspect of the present disclosure, a method for forming a
25 component of an electrochemical energy storage device is provided. The method includes: depositing a ceramic layer over a flexible substrate; and subjecting the ceramic layer to an oxidizing atmosphere at an elevated temperature.

[0010] According to an aspect of the present disclosure, a processing system for forming a component of an electrochemical energy storage device is provided. The processing

system includes a deposition module configured for depositing a ceramic layer over a flexible substrate, and an oxidation module configured for subjecting the ceramic layer to an oxidizing atmosphere at an elevated temperature.

[0011] According to an aspect of the present disclosure, an oxidation chamber
5 configured to oxidize a ceramic layer of a component of an electrochemical energy storage device is provided. The oxidation chamber includes a substrate transport mechanism. The substrate transport mechanism includes a first roll and a second roll, the substrate transport mechanism being configured to transport a flexible substrate along a transport path from the first roll to the second roll, wherein a ceramic layer is formed on the flexible substrate. The
10 oxidation chamber includes an oxidation module arranged at the transport path between the first roll to the second roll, the substrate transport mechanism being configured to subjecting the ceramic layer to an oxidizing atmosphere at an elevated temperature.

[0012] Examples are also directed at apparatuses for carrying out the disclosed methods and include apparatus parts for performing described method blocks. These method
15 blocks may be performed by way of hardware components, a computer programmed by appropriate software, by any combination of the two or in any other manner. Furthermore, examples according to the application are also directed at methods for operating the described apparatus. The method includes method blocks or operations for carrying out the functions of the apparatus.

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BRIEF DESCRIPTION OF THE DRAWINGS

[0013] So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the present disclosure, briefly summarized above, may be had by reference to typical embodiments. The accompanying
25 drawings relate to embodiments of the present disclosure and are described in the following:

[0014] Fig. 1 shows a schematic view of a processing system for forming a component of an electrochemical energy storage device according to embodiments;

[0015] Fig. 2 shows a schematic view of a processing system for forming a component of an electrochemical energy storage device according to embodiments;

[0016] Fig. 3 shows an enlarged section of the processing system shown in Fig. 2;

[0017] Fig. 4 shows a schematic view of an oxidation chamber for forming a component of an electrochemical energy storage device according to embodiments

[0018] Fig. 5 schematically shows a method for forming a component of an
5 electrochemical energy storage device according to embodiments; and

[0019] Fig. 6 schematically shows a method for forming a component of an electrochemical energy storage device according to embodiments.

DETAILED DESCRIPTION OF EMBODIMENTS

10 [0020] Reference will now be made in detail to the various embodiments of the present disclosure, one or more examples of which are illustrated in the figures. Within the following description of the drawings, the same reference numbers refer to the same components. Specifically, the differences with respect to individual embodiments are described. Each example is provided by way of explanation and is not meant as a limitation of the present
15 disclosure. Features illustrated or described as part of one embodiment can be used on or in conjunction with other embodiments to yield yet a further embodiment. Intention is that the description includes such modifications and variations.

[0021] Fig. 1 shows a processing system 100 for forming a component of an electrochemical energy storage device.

20 [0022] In the context of the present disclosure, an “electrochemical energy storage device” may be understood as an electrochemical energy store which may either be rechargeable or non-rechargeable. In this respect, the present disclosure does not distinguish between the terms “accumulator” on the one hand, and “battery” on the other hand. In the context of the present disclosure, the terms “electrochemical energy storage device”,
25 “electrochemical device” and “electrochemical cell” may be used synonymously hereinafter. The term “electrochemical energy storage device”, for instance, may also encompass a fuel cell. In embodiments described herein, an electrochemical cell may be understood to be the basic or minimum functioning unit of the energy store. In industrial practice, a multitude of electrochemical cells may be frequently connected in series or parallel in order to increase the

total energy capacity of the store. In this context, reference can be made to multiple electrochemical cells. An industrially designed battery may consequently have a single electrochemical cell or a multitude of electrochemical cells connected in parallel or in series.

[0023] In general, the electrochemical energy storage device, e.g. as an elementary
5 functioning unit, may include two electrodes of opposing polarity, namely a negative anode and a positive cathode. The cathode and the anode may be insulated by a separator arranged between the cathode and the anode to prevent short circuits between the cathode and the anode. The cell can be filled with an electrolyte. The electrolyte can be an ion conductor, which may be liquid, in gel form or occasionally solid. The separator can be ion-pervious and can permit an exchange
10 of ions between the anode and cathode in a charge or discharge cycle. The parts included in an electrochemical energy storage device may be understood as the components of the electrochemical energy storage device. Accordingly, some or each of the above described parts, including but not limited to the cathode, the anode, the electrolyte and the separator, may be considered as a component of the electrochemical energy storage device.

15 [0024] As shown in Fig. 1, the processing system 100 may include a deposition module 102. The deposition module 102 can be configured to deposit a ceramic layer 52 over or on a flexible substrate 111. Specifically, the flexible substrate can have a first side and/or a second side opposite to the first side. The ceramic layer 52 can be deposited over or on at least one of the first side and a second side of the flexible substrate 111.

20 [0025] In the context of the present disclosure, a “ceramic layer”, such as the ceramic layer 52, can be understood as a layer including or formed by a ceramic material. A “ceramic material” can be understood as is an inorganic, non-metallic, solid material including metal, non-metal or metalloid atoms primarily held in ionic and covalent bonds. In the context of the present disclosure, a ceramic material can be particularly understood as a dielectric
25 material that specifically includes metal and oxygen atoms, such as, e.g., aluminum oxide, aluminum nitride etc. According to embodiments described herein, the ceramic layer 52 can be an aluminum oxide layer.

[0026] According to embodiments described herein, the ceramic material can be at least one electrically non-conductive or just very poorly conductive oxide of the metals
30 aluminum, silicon, lead, zirconium, titanium, hafnium, lanthanum, magnesium, zinc, tin, cerium, yttrium, calcium, barium, strontium and combinations thereof. Despite silicon often

being referred to as metalloid, in the context of the present disclosure silicon shall be included whenever reference is made to a metal. According to embodiments described herein, the component of the electrochemical energy storage device may be optimized for electrochemical cells involving strongly alkaline electrolytes by choosing particularly alkali-resistant input materials. For instance, zirconium or titanium may be used instead of aluminum or silicon as an inorganic component to form the ceramic layer 52. In such a case, the ceramic layer 52 could include zirconium oxide or titanium oxide instead of aluminum oxide or silicon oxide.

[0027] According to embodiments described herein, the ceramic layer 52 can be a porous layer or have a porosity. In particular, the ceramic layer 52 can be porous such that certain elements can pass through the ceramic layer 52.

[0028] The flexible substrate 111 may particularly embrace flexible substrates such as a plastic film, a web, a foil, flexible glass or a strip. The term flexible substrate may also embrace other types of flexible substrates. A flexible substrate, as used with the embodiments described herein, can be bendable. The term “flexible substrate” or “substrate” may be synonymously used with the term “foil” or the term “web”. In particular, embodiments described herein can be utilized for coating any kind of flexible substrate, e.g. for manufacturing flat coatings with a uniform thickness, or for manufacturing coating patterns or coating structures in a predetermined shape on the flexible substrate or on top of an underlying coating structure. In addition to the ceramic layer, electronic devices and structures may be formed on the flexible substrate by masking, etching and/or depositing.

[0029] According to embodiments described herein, the flexible substrate 111 may include a polymer material selected from the group of: polyacrylonitrile, polyester, polyamide, polyimide, polyolefin, polytetrafluoroethylene, carboxymethyl cellulose, polyacrylic acid, polyethylene, polyethylene terephthalate, polyphenyl ether, polyvinyl chloride, polyvinylidene chloride, polyvinylidene fluoride, poly(vinylidene fluoride-co-hexafluoropropylene), polylactic acid, polypropylene, polybutylene, polybutylene terephthalate, polycarbonate, polytetrafluoroethylene, polystyrene, acrylonitrile butadiene styrene, poly(methyl methacrylate), polyoxymethylene, polysulfone, styrene-acrylonitrile, styrene-butadiene rubber, ethylene vinyl acetate, styrene maleic anhydride, and combinations thereof. Any other polymer materials that are stable in, for example, the strongly reducing conditions found in lithium based electrochemical energy storage devices may be used as well. According to embodiments described herein, the flexible substrate 111 and/or the ceramic layer 52 can be optimized for

electrochemical energy storage devices involving strongly alkaline electrolytes by choosing particularly alkali-resistant input materials. For instance, the flexible substrate 111 may include a polyolefin or a polyacrylonitrile instead of polyester.

[0030] In the case of separators, the flexible substrate 111 may be made from
5 and/or include microporous polyethylene, polypropylene, polyolefin, and/or a laminate thereof.

[0031] In case of a cathode, the flexible substrate 111 may be made from and/or include aluminum. In this case, a cathode layer may be formed on the flexible substrate 111. The ceramic layer 52 can be formed on the cathode layer. For instance, the flexible substrate 111 in case of a cathode can have a thickness of 5 to 12 μm and/or the cathode layer can have
10 a thickness of up to 100 μm . Additionally or alternatively, the flexible substrate 111 can be or include a polymer material as described herein, e.g. polyester, on which a layer of aluminum is deposited. The polymer substrate may be thinner than e.g. the aluminum substrate and/or the deposited layer of aluminum. The deposited layer of aluminum can have a thickness of about 0.5 μm to about 1 μm . When practicing embodiments, a thickness of the cathode can be
15 reduced.

[0032] In case of an anode, the flexible substrate 111 may be made from and/or include copper. In this case, an anode layer may be formed on the flexible substrate 111. The ceramic layer 52 can be formed on the anode layer. For instance, the flexible substrate 111 in case of an anode can have a thickness of 5 to 12 μm and/or the anode layer can have a thickness
20 of up to 100 μm . Additionally or alternatively, the flexible substrate 111 can be or include a polymer material as described herein, e.g. polyester, on which a layer of copper is deposited. The polymer substrate may be thinner than e.g. the copper substrate and/or the deposited layer of copper. The deposited layer of copper can have a thickness of about 0.5 μm to about 1 μm . When practicing embodiments, a thickness of the anode can be reduced.

[0033] According to embodiments described herein, the material of the flexible substrate 111, specifically the polymer material, may have a high melting point, such as equal to or greater than 200 $^{\circ}\text{C}$. Components of electrochemical energy storage devices including polymer materials with a high melting point may be useful in electrochemical energy storage devices having a fast charging cycle. In practice, particularly by virtue of the high thermal
30 stability of a component including a polymer material having a high melting point according to embodiments described herein, an electrochemical energy storage device equipped with such a

component may not be so thermally sensitive and may be able to tolerate a temperature increase due to rapid charging without adverse changes to the component or damage to the electrochemical energy storage device. When practicing embodiments, a faster charging cycle may be achieved, which may be useful in electric vehicles, which may be charged within a shorter period of time.

[0034] According to embodiments described herein, the flexible substrate 111 with or without the ceramic layer 52 may have a porosity in the range from 10% to 90%, specifically in the range from 40% to 80%. The flexible substrate 111 and/or the ceramic layer 52 may provide in practice a pathway for electrolyte and may reduce an electrolyte penetration time. In the context of the present disclosure, “porosity”, such as the porosity of the flexible substrate 111 and/or the ceramic layer 52, may relate to the accessibility of open pores. For instance, a porosity can be determined via common methods, such as, e.g., by the method of mercury porosimetry and/or may be calculated from the volume and the density of the materials used on the assumption that all the pores are open pores.

[0035] According to embodiments described herein, the electrochemical energy storage device can be a Li-ion battery. In Li-ion batteries, the flexible substrate 111 may often be made from microporous polyethylene and polyolefin. During electrochemical reactions of charging and discharging cycles Li-ions are transported through the pores in the flexible substrate 111 and/or the ceramic layer 52 between the two electrodes of the Li-ion battery. High porosity may increase ionic conductivity. However, some flexible substrates 111 with high porosity may be susceptible to electrical shorts when, for instance, Li-dendrites formed during cycling create shorts between the electrodes.

[0036] The present disclosure may provide very thin components of electrochemical energy storage device, such as very thin separators. When practicing embodiments, a proportion of the constituents of an electrochemical energy storage device, which do not contribute to the activity of the electrochemical energy storage device, can be reduced. Further, a reduction in the thickness may simultaneously bring about an increase in the ion conductivity. The components according to embodiments described herein may permit for an increased density in, for instance, a battery stack, so that a large amount of energy can be stored in the same volume. When practicing embodiments, a limiting current density can like-wise be increased, through enlargement of the electrode area.

[0037] Embodiments described herein may be used for the production of separators. The separators may be separate from the electrochemical energy storage device or integrated directly into an electrochemical energy storage device, such as, for instance, lithium-ion batteries having integrated separators. In integrated separator applications, a single-layer separator or a multi-layer separator may be formed directly on an electrode of the electrochemical energy storage device. Further, the ceramic layer 52 may be coated on an electrode of the electrochemical energy storage device, such as an anode or a cathode. Accordingly, the component of the electrochemical energy storage device, can be a separator or separator film, an electrolyte, an anode and/or a cathode.

[0038] According to embodiments described herein, the ceramic layer 52 may be formed by evaporating a metal. Specifically, the ceramic layer 52 may be formed by evaporating a metal in an inductively heated crucible. Further, a process gas, such as, e.g., oxygen may be supplied for forming the ceramic layer 52. According to embodiments described herein, the ceramic layer 52 may be formed by reactive evaporation. When practicing embodiments, very high coating speeds, as compared to conventional separator coating techniques such as dip-coating, may be achieved. Specifically, coating speeds may vary depending on the thickness and type of ceramic material to be formed on the flexible substrate 111.

[0039] According to embodiments described herein, a thickness of the ceramic layer 52 formed on the flexible substrate 111 can be equal to or greater than 25 nm, specifically equal to or greater than 50 nm, particularly equal to or greater than 100 nm, and/or equal to or smaller than 1000 nm, specifically equal to or smaller than 500 nm, particularly equal to or smaller than 150 nm. When practicing embodiments, a very high energy density in an electrochemical energy storage device can be achieved.

[0040] When forming the ceramic layer 52 by evaporation, specifically by reactive evaporation, the ceramic layer 52 may not be formed with full stoichiometry or formed non-stoichiometry. In the context of the present disclosure, “stoichiometry”, such as a stoichiometry of the ceramic layer 52, may be understood as the calculation of the relative quantities of reactants and products in chemical reactions. Accordingly, “non-stoichiometric” or “not full stoichiometric” can refer to cases in which the product does not include all reactants. In the example of aluminum oxide being the material of the ceramic layer 52, a full stoichiometric reaction may be: $4\text{Al} + 3\text{O}_2 = 2\text{Al}_2\text{O}_3$. If the aluminum oxide is not formed with full

stoichiometry or non-stoichiometric, the product of the reaction may be, e.g., $\text{Al}_2\text{O}_{2.5}$. Accordingly, any composition of AlO_x with $x \neq 1.5$ can be considered as non-stoichiometric or not formed with full stoichiometry. In such a non-stoichiometric ceramic layer, there may be unbound excess atoms that may react with elements of the electrochemical energy storage device, specifically during charge and/or discharge of the electrochemical energy storage device. In the example of Li-ion batteries, the unbound excess atoms that may react with Li-ions traversing through the ceramic layer, such as during charge and/or discharge of the Li-ion battery. In the example of aluminum oxide being the material of the ceramic layer 52, the unbound excess atoms may be Al.

10 [0041] According to embodiments described herein, the processing system 100 can include an oxidation module 150. The oxidation module 150 can be configured to subject the ceramic layer 52 to an oxidizing atmosphere. According to embodiments described herein, the ceramic layer 52 can be subjected to an oxidizing atmosphere, specifically at an elevated temperature. When practicing embodiments, the stoichiometry of the ceramic layer 52 can be improved. According to beneficial embodiments, a fully stoichiometric ceramic layer 52 can be obtained in practice.

[0042] In the context of the present application, an “oxidizing atmosphere”, such as the oxidizing atmosphere the ceramic layer 52 can be subjected to, can be understood as an atmosphere facilitating an oxidation reaction, e.g. to improve the stoichiometry of the ceramic layer 52. According to embodiments described herein, the oxidizing atmosphere can contain more than 20 vol.-% oxygen.

[0043] In the example of aluminum oxide as the material of the ceramic layer 52, the aluminum oxide may oxidize when subjected to the oxidizing atmosphere so that the amount of unbound excess Al atoms is reduced and/or the aluminum oxide includes an increased amount of Al_2O_3 . According to embodiments described herein, the aluminum oxide layer can be subjected to the oxidizing atmosphere in such a manner that a stoichiometry of the aluminum oxide layer is improved. Accordingly, less elements of the electrochemical energy storage device, such as the above described Li-ion, may react with the ceramic layer 52. When practicing embodiments, higher discharge and/or recharge rates, a higher voltage and/or an improved life span may be obtained. Accordingly, an improved charge transport, an increased voltage and/or an extended cycle life can be obtained in practice.

[0044] Further, mechanical robustness of the ceramic layer 52 can be improved. When practicing embodiments, manufacture, post-processing and storing of the component of the electrochemical energy storage device and of the electrochemical energy storage device as such can be improved. In particular, the improved robustness of the ceramic layer 52 may facilitate winding and/or re-winding of the ceramic layer 52 formed on the flexible substrate 111.

[0045] According to embodiments described herein, the ceramic layer 52 can be subjected to the oxidizing atmosphere at an elevated temperature. In the context of the present disclosure, an “elevated temperature”, such as the elevated temperature at which the ceramic layer 52 can be subjected to the oxidizing atmosphere, can be understood as a temperature being elevated, i.e. raised, with respect to a surrounding temperature of an environment. Accordingly, an elevated temperature can be understood as a temperature above room temperature or ambient temperature. There may also be devices be used to raise a surrounding temperature to the elevated temperature. For instance, a heating device or heating assembly may be employed to obtain the elevated temperature.

[0046] According to embodiments described herein, an elevated temperature may be equal to or greater than ambient temperature, and/or equal to or greater than 23 °C, specifically equal to or greater than 50 °C, particularly equal to or greater than 80 °C. Additionally or alternatively, the elevated temperature is equal to or greater than 50 °C, specifically equal to or greater than 60 °C, particularly equal to or greater than 80 °C, and/or equal to or smaller than 180 °C, specifically equal to or smaller than 120 °C, particularly equal to or smaller than 100 °C.

[0047] Such an elevated temperature may increase a speed of oxidization, i.e. the higher the temperature gets the faster the oxidation process may be. Nonetheless, there may be further constraints that may provide an upper limit for the elevated temperature. In the application of electrochemical energy storage device there may be hard constraints for the application of an elevated temperature. As outlined above, the flexible substrate 111 may deform when subjected to temperature. Although outlined above, that a material for the flexible substrate 111 may be used that has a melting point of about 200 °C, many flexible substrates do not have such a high melting point. Further, Li has a melting point of about 180 °C, which may limit the temperature range for the elevated temperature as well. Accordingly, the use of an elevated temperature for forming or post-processing of a ceramic layer for a component of

an electrochemical energy storage device, in particular of a Li-ion battery, is usually counterintuitive. The present application introduces the use of an oxidation atmosphere at an elevated temperature to improve the stoichiometry of the ceramic layer.

[0048] Fig. 1 shows the oxidation module 150 as being arranged downstream of the deposition module 102. While such an arrangement may be used according to embodiments described herein, other configurations may be possible as well. For instance, the oxidation module 150 may be arranged in-line, i.e. in-line with the deposition module 102. In that a case, the oxidation module 150 and the deposition module 102 can be in the same processing system or processing chamber. Further, the oxidation module 150 may be arranged off-line, i.e. in a different line as the deposition module 102. In this case, the oxidation module 150 and the deposition module 102 can be in different processing systems or processing chambers. For instance, a separate oxidation chamber may be provided for the oxidation module 150. Furthermore, the deposition module 102 can be provided in a first processing chamber and the oxidation module 150 can be provided in a second chamber of the same processing system.

[0049] The flexible substrate 111 may be moved while being processed in the vacuum processing chamber, e.g. from the deposition module 102 to the oxidation module 150. According to embodiments described herein, a substrate transport mechanism may be provided. For example, the flexible substrate 111 may be transported along a transport path P past the deposition module 102 and/or the oxidation module 150.

[0050] As shown in Fig. 1, a first substrate support 22 and/or a second substrate support 24 arranged at a distance from the first substrate support 22 may be provided. The first substrate support 22 and/or the second substrate support 24 may also be referred to as rollers, e.g. a first roller and/or a second roller. The first roll 22 and the second roll 24 may be part of the substrate transport mechanism. According to embodiments described herein, the flexible substrate 111 can be transported from the first roll 22 to the second roll 24. The flexible substrate 111 may be carried and/or conveyed from the first roll 22 to the second roll 24 along the transport path P (indicated by the circle having a dot in the center so as to indicate the transport path P being perpendicular to the plane of projection). According to embodiments described herein, the substrate transport mechanism can be configured to transport the flexible substrate 111 along the transport path P from the first roll 22 to the second roll 24. The deposition module 102 and/or the oxidation module 150 can be provided at a position between the first roll 22 and the second roll 24. According to embodiments described herein, the

deposition module 102 and/or the oxidation module 150 can be arranged along the transport path P. According to embodiments described herein, the ceramic layer 52 can be formed while the flexible substrate 111 is transported from the first roll 22 to the second roll 24. According to embodiments described herein, the ceramic layer 52 can be subjected to an oxidizing atmosphere while the flexible substrate 111 is transported from the first roll 22 to the second roll 24.

[0051] In some implementations, the flexible substrate 111, may be unwound from a storage roller, may be transported on the outer surface of a coating drum, and may be guided along the outer surfaces of further rollers. The coated flexible substrate may be wound onto a wind-up spool.

[0052] In the context of the present disclosure, a “roll”, “roller” or “roller device”, e.g. as part of a roller assembly, may be understood as a device, which provides a surface, with which a substrate (or a part of a substrate), such as the flexible substrate 111 (or a part of the flexible substrate 111) may be in contact during the presence of the substrate in a deposition arrangement (such as a deposition apparatus or deposition chamber). At least a part of the roller device may include a circular-like shape for contacting the substrate. In some embodiments, the roller device may have a substantially cylindrical shape. The substantially cylindrical shape may be formed about a straight longitudinal axis or may be formed about a bent longitudinal axis. According to some embodiments, the roller device as described herein may be adapted for being in contact with the flexible substrate. The roller device as referred to herein may be a guiding roller adapted to guide a substrate while the substrate is coated (or a portion of the substrate is coated) or while the substrate is present in a processing apparatus, a spreader roller adapted for providing a defined tension for the substrate to be coated, a deflecting roller for deflecting the substrate according to a defined travelling path or the like.

[0053] According to embodiments described herein, the processing system may be configured for processing a flexible substrate 111 with a length of 500 m or more, 1000 m or more, or several kilometres. The substrate width can be 100 mm or more, 300 mm or more, 500 mm or more, or 1 m or more. The substrate width can be 5 m or less, particularly 2 m or less. Typically, the substrate thickness can be 5 μm or more and 200 μm or less, particularly from 15 μm to 20 μm .

[0054] Fig. 2 shows a schematic view of a processing system 100 for depositing a ceramic material on a surface of a flexible substrate 111. The processing system 100 can include a loading/unloading chamber 101. The loading/unloading chamber 101 can be configured to load/unload the flexible substrate 111 into and/or from the processing system 100.

5 According to embodiments described herein, the loading/unloading chamber may be held under vacuum during processing of the flexible substrate 111. A vacuum device 190, such as a vacuum pump, can be provided to evacuate the loading/unloading chamber 101.

[0055] According to embodiments described herein, the loading/unloading chamber 101 can include an un-winding module 110 and/or a re-winding module 130. The un-
10 winding module 110 can include an unwind roll for unwinding the flexible substrate 111. During processing, the flexible substrate 111 may be un-wound (indicated by arrow 113) and/or guided by one or more guide rolls 112 to a coating drum 120. After being processed, the flexible substrate 111 may be wound (arrow 114) on a re-wind roll in the re-winding module 130.

[0056] Further, the loading/unloading chamber 101 may include a tension module
15 180, for instance, including one or more tension rollers. Additionally or alternatively, the loading/unloading chamber 101 may also include a pivot device 170, such as, for instance, a pivot arm. The pivot device 170 can be configured to be moveable with respect to the re-winding module 130.

[0057] According to embodiments described herein, the un-winding module 110,
20 the re-winding module 130, the guide rolls 112, the pivot device 170, tension module 180 can be part of the substrate transport mechanism and/or the roller assembly.

[0058] According to embodiments described herein, the processing system 100 can include a deposition chamber 103 or evaporation chamber 103. The deposition chamber 103 can include the deposition module 102. The deposition module 102 can be similar to or the
25 same as the deposition module 102 described with particular reference to Fig. 1. The deposition chamber 103 may be evacuated by the vacuum device 190 that may also be used to evacuate the loading/unloading chamber 101. Additionally or alternatively the deposition chamber 103 may have a vacuum device that is separate from the vacuum device 190 that may also be used to evacuate the loading/unloading chamber 101.

[0059] As exemplarily shown in Fig. 2, the deposition module 102 may include an evaporation device 140. The evaporation device 140 can be configured to evaporate a material, specifically a metal. According to embodiments described herein, the evaporation device 140 may include one or more evaporation boats. The evaporation device 140 can further include
5 one or more wires to be fed into the evaporation device 140. Specifically, there can be one wire for each evaporation boat. The one or more wires can include and/or be made of the material to be evaporated. Specifically, the one or more wires can supply the material to be evaporated.

[0060] According to embodiments described herein, the evaporation device 140 may be one or more inductively heated crucibles. The inductively heated crucible may, for
10 instance, be configured for evaporating a metal in a vacuum environment by RF induction-heating, in particular by MF induction-heating. Further, the metal may be provided in crucibles that are exchangeable, such as, for example in one or more graphite vessels. The exchangeable crucible may include an insulating material that surrounds the crucible. One or more induction coils may be wrapped around the crucible and the insulating material. According to
15 embodiments described herein, the one or more inductive coils may be water cooled. Where exchangeable crucibles are used, no wire needs to be fed into the evaporation device 140. The exchangeable crucibles may be pre-loaded with a metal and may be replaced or refilled periodically. Specifically, providing the metal in batches has the advantage of accurately controlling the amount of metal being evaporated.

[0061] In contrast to conventional evaporation methods that use resistance heating
20 of crucibles to evaporate metals, using an inductively heated crucible allows for the heating process to be generated inside of the crucible, instead of by an external source via heat conduction. The inductively heated crucible has the advantage that all the walls of the crucible are heated very rapidly and evenly. The evaporation temperature of the metal may be controlled
25 more closely than with conventional resistance heated crucibles. When using an inductively heated crucible heating the crucible above the evaporation temperature of the metal may be unnecessary. When practicing embodiments, a more controlled and efficient evaporation of the metal in order for the ceramic layer formed on a flexible substrate to be more homogenous may be provided. Close control of the temperature of the crucible may also prevent/reduce pinholes
30 and through-hole defects in the ceramic layer by diminishing the likelihood of splashing of the evaporating metal. Pinhole and through-hole defects in separators may cause shorts in electrochemical cells.

[0062] According to embodiments described herein, the inductively heated crucible may, for instance, be surrounded by one or more induction coils (not shown in the Figs.). The induction coils may be an integral part of the inductively heated crucible. Further, the induction coils and the inductively heated crucible may be provided as separate parts.

5 Providing the inductively heated crucible and the induction coils separately may allow for easy maintenance of the evaporation apparatus.

[0063] According to embodiments described herein, the evaporation source can include one or more electrode beam sources. The one or more electrode beam sources can provide one or more electrode beams to evaporate the material to be evaporated.

10 [0064] According to embodiments described herein, a power source 240 (see in Fig. 3) may be provided. The power source 240 may be connected to the induction coils. The power source can be an AC power source that can be configured to provide electricity with a low voltage but high current and high frequency. Further, a reaction power may be increased, for instance, by including a resonant circuit. According to embodiments described herein, in
15 addition or alternatively to electrically conductive materials, the inductively heated crucible may, for instance, include ferromagnetic materials. Magnetic materials may, for instance, improve the induction heat process and may allow for a better control of the evaporation temperature of metal.

[0065] According to embodiments described herein, the coating drum 120 of the
20 processing system 100 may separate the loading/unloading chamber 101 from the evaporation chamber 103. The coating drum 120 can be configured to guide the flexible substrate 111 into the evaporation chamber 103. Generally, the coating drum 120 can be arranged in the processing system so that the flexible substrate 111 can pass over the evaporation module 102. According to embodiments described herein, the coating drum 120 may be cooled.

25 [0066] The deposition module 102 may include a plasma source 108 configured to produce a plasma between the evaporation device 140 and the coating drum 120. The plasma source 108 may, for instance, be an electron beam device configured to ignite a plasma with an electron beam. According to further embodiments herein, the plasma source may be a hollow anode deposition plasma source. The plasma may help to prevent/reduce pinholes and through-
30 hole defects in the porous coating on the substrate by further diminishing the likelihood of splashing of the evaporating metal. The plasma may also further excite the particles of the

evaporated metal. According to embodiments described herein, the plasma may increase the density and uniformity of the porous coating deposited on the flexible substrate.

[0067] According to embodiments described herein, the deposition module 102 can include a gas supply for supplying a process gas. The gas supply can include a gas introduction
5 device 107. The gas introduction device 107 can be arranged for controllably introducing the process gas into the deposition module 102 and/or the deposition chamber 103. The gas introduction device may, for instance, include a nozzle and a supply tube connected to, for example, a process gas supply for providing the process gas into the deposition module 102 and/or deposition chamber 103.

10 [0068] The process gas can be a reactive gas. Specifically, the process gas can be a reactive gas that reacts with the metal evaporated by the evaporation device 140. For instance, the process gas can be and/or include oxygen, ozone, argon and combinations thereof.

[0069] For the case of oxygen being included in the process gas, the oxygen gas may, for example, react with the evaporated metal to form the ceramic layer 52 on the flexible
15 substrate 111. The components of the electrochemical energy storage device, such as the separator or separator film, the electrolyte, the cathode and the anode, may include AlO_x . The metal such as aluminum may be evaporated by the inductively heated crucible and oxygen may be supplied to the evaporated metal via the gas introduction device.

[0070] According to embodiments described herein, the processing system may
20 include the oxidation module 150. The oxidation module 150 can be an annealing module for annealing the ceramic layer 52. The oxidation module 150 can be similar to or the same as the oxidation module 150 described with particular reference to Fig. 1. As exemplarily shown in Fig. 2, the oxidation module 150 can be arranged downstream of the deposition chamber 103. The oxidation module 150 can be configured to subject the ceramic layer to an oxidizing
25 atmosphere and/or an annealing atmosphere, specifically over an oxidation distance and/or an annealing distance. The oxidation distance and/or annealing distance can be long enough to obtain the intended amount of oxidation and/or annealing.

[0071] According to embodiments described herein, the oxidation module 150 can include a gas assembly 151. The gas assembly 151 can be configured to supply an oxidation
30 gas, such as oxygen. According to embodiments described herein, the oxidation module 150

can include a heating assembly (not shown). The heating assembly can be configured to elevate a temperature of at least one of the supplied oxidation gas, the flexible substrate 111 and the ceramic layer 52.

[0072] According to embodiments described herein, the oxidation module 150 can include a suction device 152. The suction device 152 can be configured to suck excess oxidation gas, i.e. oxidation gas that is not used to oxide the ceramic layer 52. The suction device 152 can be arranged, with respect to the flexible substrate 111, opposite to the gas assembly 151. Accordingly, process gas supplied by the gas assembly 151 can be provided to the ceramic layer 52, traverse the flexible substrate 111, and be sucked by the suction device 152. When practicing embodiments, pollution of the processing system 100 can be prevented.

[0073] The oxidation module 150 can further include a plasma source (not shown in Fig. 2, see Fig. 4). The plasma source can be the plasma source 153 of the oxidation chamber 200 described herein with particular reference to Fig. 4. When practicing embodiments, an oxidation distance and/or annealing distance can be reduced.

[0074] Fig. 3 shows an enlarged section of the processing system 100 shown in Fig. 2. According to embodiments described herein, the processing system 100 may include a control system 220. The control system 220 may be connected to at least one of the deposition module 102, the oxidation module 150, the gas introduction device 107, the plasma source 108 and the power source 240. According to embodiments described herein, the control system 220 can be configured to adjust at least one of a power provided to the deposition module 102, power provided to the plasma source 108, an amount of the processing gas and/or an orientation of a gas flow of the processing gas introduced into the deposition module 102 by the gas introduction device 107. According to embodiments described herein, the control system 220 can be configured to, additionally or alternatively, adjust at least one of an amount of the oxidation gas and/or an orientation of a gas flow of the oxidation gas supplied by the oxidation module 150, and a suction force of the suction device 152.

[0075] According to embodiments described herein, the gas introduction device 107 may be arranged to provide a gas flow of the process gas in a direction approx. parallel to an evaporation direction 230 of the metal. According to embodiments described herein, the orientation of the gas flow provided by the gas introduction device may be adjusted depending on at least one of the uniformity and composition of the ceramic layer 52. When practicing

embodiments, a more efficient reaction between the reactive gas and the evaporated metal for forming the ceramic layer can be ensured. Arranging the gas introduction device 107 to introduce a reactive gas in a direction essentially parallel to the evaporation direction 230 of the metal from the evaporation device 140 may also help to better control the coating process by
5 being able to more accurately control the amount of process gas which interacts with the evaporated metal.

[0076] According to embodiments described herein, the plasma 210 may be guided in a direction essentially perpendicular to the evaporation direction 230 of the metal. When practicing embodiments, splashing of the evaporating metal may be prevented and/or pinhole
10 defects of the ceramic layer can be reduced.

[0077] Although the oxidation module 150 is shown in Figs. 1 to 3 as being arranged in-line with the deposition module 102, the oxidation module 150 can be, as outlined above, arranged off-line. For instance, an oxidation chamber 200 can be provided in which the oxidation module 150 can be arranged. The oxidation chamber 200 can be separate from
15 deposition chamber 103. Further, the oxidation chamber 200 can be separate from processing system 100. Furthermore, the processing system 100 can be a multi-chamber system including multiple processing chambers, such as the deposition chamber 103 and/or oxidation chamber 200. Further, the processing system 100 can include a storage chamber in which the re-wound flexible substrate 111 having the ceramic layer 52 deposited on the flexible substrate 111 can
20 be stored before the re-wound flexible substrate 111 having the ceramic layer 52 deposited on the flexible substrate 111 can be transferred to the oxidation chamber 200.

[0078] Fig. 4 shows an oxidation chamber 200 according to embodiments. The oxidation chamber 200 can include the oxidation module 150 and/or a substrate transport mechanism.

25 [0079] The substrate transport mechanism can include a first roll 222 and/or a second roll 224. The first roll 222 and/or the second roll 224 of the oxidation chamber 200 can be similar to or the same as the first roll 22 and/or the second roll 24 of the processing system 100 described e.g. with particular reference to Fig. 1. Furthermore, the oxidation chamber 200 can include a similar or the same substrate transport mechanism and/or roller assembly as the
30 processing system 100 described e.g. with particular reference to Fig. 2. Accordingly, the substrate transport mechanism and/or roller assembly of the oxidation chamber 200 can include

the same, similar or corresponding parts as the substrate transport mechanism and/or roller assembly as the processing system 100, particular including the un-winding module 110, the re-winding module 130, the guide rolls 112, the pivot device 170, and the tension module 180. The substrate transport mechanism can be configured to transport a flexible substrate 111 along
5 a transport path P' from the first roll 222 to the second roll 224. The ceramic layer 52 can be formed on the flexible substrate 111.

[0080] According to embodiments described herein, the oxidation module 150 can be arranged at the transport path P between the first roll 22 and the second roll 24. The oxidation module 150 can be configured to subject the ceramic layer 52 to an oxidizing atmosphere at an
10 elevated temperature.

[0081] Further, the oxidation module 150 in the oxidation chamber 200 can further include the same or similar parts as described above with particular reference to Figs. 1 to 3, specifically including the gas assembly 151 and/or the suction device 152. Further, the oxidation module 150 can include a plasma source 153. The plasma source 153 can be
15 configured to produce a plasma between the gas assembly 151 and the flexible substrate 111. The plasma source 153 may, for instance, be an electron beam device configured to ignite a plasma with an electron beam. According to further embodiments herein, the plasma source may be a hollow anode deposition plasma source. Further, the plasma source 153 can be the same as or similar to the plasma source 108 of the deposition module 102 described herein with
20 particular reference to Figs. 2 and 3. The plasma may ionize and/or heat the oxidation gas supplied by the gas assembly 151. Accordingly, an oxidation rate of the ceramic layer 52 may be increased. When practicing embodiments, a fully stoichiometric ceramic layer can be obtained.

[0082] According to embodiments described herein, the oxidation module 150 can
25 include a heating assembly 154. The heating assembly 154 can be configured to elevate a temperature of at least one of the oxidation chamber 200, the oxidizing atmosphere, the flexible substrate 111 and the ceramic layer 52. Specifically, the heating assembly 154 can be configured to create or generate the elevated temperature. Accordingly, an oxidation rate of the ceramic layer 52 may be increased. When practicing embodiments, a fully stoichiometric
30 ceramic layer can be obtained.

[0083] Although the plasma source 153 and the heating assembly 154 are shown in Fig. 3 as part of the oxidation module 150 being arranged in the oxidation chamber 200, the plasma source 153 and/or the heating assembly 154 can also be present in oxidation modules 150 outside the oxidation chamber 200, such as in-line oxidation modules 150. For instance, the plasma source 153 and/or the heating assembly 154 can also be part of the oxidation modules 150 described herein with particular reference to Figs. 1 to 3. In the case that the heating assembly 154 is arranged in a processing chamber different to the oxidation chamber 200, the heating assembly 154 can be configured to heat this processing chamber.

[0084] Fig. 5 shows a flow diagram of a method 500 for forming a component of an electrochemical energy storage device. The method can include at least one of operations 510 and 520. According to operation 510, a ceramic layer 52 is deposited over a flexible substrate 111. According to operation 520, the ceramic layer 52 is subjected to an oxidizing atmosphere at an elevated temperature. When practicing embodiments, a ceramic layer having improved stoichiometry can be obtained.

[0085] Fig. 6 schematically shows a method 300 for forming a component of an electrochemical energy storage device. According to embodiments described herein. The method 300 can include providing 310 a flexible substrate having a front side and a back side. According to embodiments described herein, providing a flexible substrate may include guiding the flexible substrate from an un-winding module to a re-winding module via a coating drum of an evaporation apparatus.

[0086] According to embodiments described herein, the method may further include evaporating 320 a metal in an inductively heated crucible. Specifically, According to embodiments described herein, aluminum and/or silicon may be evaporated by an inductively heated crucible. In embodiments herein, the method further includes applying 330 a ceramic layer to at least one of the front side and back side of the flexible substrate.

[0087] The evaporated metal may react with a reactive gas to form the porous coating on the flexible substrate. The metal may be evaporated in a vacuum environment. For example, evaporated aluminum may react with oxygen to form a porous AlO_x layer on the flexible substrate.

[0088] According to embodiments described herein, evaporating the metal in the inductively heated crucible may further include sensing 340 an evaporation temperature at which the metal evaporates and adjusting a power provided to evaporate the metal in the inductively heated crucible depending on the sensed evaporation temperature. Monitoring and
5 adjusting the evaporation temperature may improve the energy efficiency of the method for forming the component of the electrochemical energy storage device and/or may help to prevent any pinhole defects of the porous coating applied to the flexible substrate.

[0089] In embodiments described herein, the ceramic layer applied to the flexible substrate may have a thickness from approx. 25 nm to approx. 300 nm, such as, for instance,
10 from 100 nm to 200 nm.

[0090] According to embodiments described herein, evaporating the metal in the inductively heated crucible may further include providing 350 a process gas such as, for example, oxygen to the evaporated metal. The reactive gas may be provided in a direction essentially parallel to the evaporation direction of the metal.

[0091] The method for forming a component of an electrochemical energy storage device may further include providing 360 a plasma between the evaporated metal and the flexible substrate. The plasma may increase the density of the porous coating on the flexible substrate and may also help to reduce pinhole defects of the porous coating. Specifically, According to embodiments described herein the plasma may be provided by, for instance, an
15 electron beam device or a hollow anode deposition plasma source. The density of the porous coating may be influenced by the density of the plasma.

[0092] The stoichiometry of the deposited porous layer on the flexible substrate may, for instance, be influenced by the evaporation rate of the metal and the amount of process gas provided to the evaporated metal. Further aspects that may influence the stoichiometry of
25 the deposited porous layer may be the pressure differential between the vacuum inside of the evaporation chamber and the pressure of the surrounding atmosphere. Accordingly, as outlined herein, the ceramic layer 52 may be deposited non-stoichiometrically or not with full stoichiometry.

[0093] According to embodiments described herein, the method for forming a
30 component of an electrochemical energy storage device may include subjecting 370 the ceramic

layer 52 to an oxidizing atmosphere at an elevated temperature. When practicing embodiments, a stoichiometry of the ceramic layer can be improved. Even a fully stoichiometric ceramic layer may be obtained in practice.

[0094] This written description uses examples to disclose the disclosure, including
5 the best mode, and also to enable practicing the described subject-matter, including making and using any apparatus or system and performing any incorporated methods. Embodiments described herein provide an improved method and apparatus for producing a separator having a high porosity for good ionic conductivity, complex pore structure with no/reduced pinhole or through-hole defects to suppress shorts, excellent thermal and mechanical stability and can be
10 produced at low cost. While various specific embodiments have been disclosed in the foregoing, mutually non-exclusive features of the embodiments described above may be combined with each other. The patentable scope is defined by the claims, and other examples are intended to be within the scope of the claims if the examples have structural elements that do not differ from the literal language of the claims, or if the examples include equivalent structural elements
15 with insubstantial differences from the literal language of the claims.

CLAIMS

1. A method for forming a component of an electrochemical energy storage device, comprising:

depositing a ceramic layer (52) over a flexible substrate (111); and

5 subjecting the ceramic layer (52) to an oxidizing atmosphere at an elevated temperature.

2. The method according to claim 1, wherein the ceramic layer (52) is an aluminum oxide layer.

10 3. The method according to claim 2, wherein the aluminum oxide layer is subjected to the oxidizing atmosphere in such a manner that a stoichiometry of the aluminum oxide layer is improved.

4. The method according to any one of claims 1 to 3, wherein the electrochemical energy
15 storage device is a Li-ion battery.

5. The method according to any one of claims 1 to 4, wherein the component is a separator.

6. The method according to any one of claims 1 to 4, wherein the component is an
20 electrode.

7. The method according to any one of claims 1 to 6, wherein the elevated temperature is equal to or greater than 50 °C, specifically equal to or greater than 60 °C, particularly equal to or greater than 80 °C, and/or equal to or smaller than 180 °C, specifically equal to or smaller
25 than 120 °C, particularly equal to or smaller than 100 °C.

8. The method according to any one of claims 1 to 7, wherein the oxidizing atmosphere contains more than 20 vol.-% oxygen.

9. The method according to any one of claims 1 to 8, further comprising:

transporting the flexible substrate (111) from a first roll (22) to a second roll (24), the ceramic layer (52) being formed while the flexible substrate (111) is transported from the first
5 roll (22) to the second roll (24).

10. The method according to claim 9, wherein the ceramic layer (52) is subjected to an oxidizing atmosphere while the flexible substrate (111) is transported from the first roll (22) to the second roll (24).

10

11. A processing system (100) for forming a component of an electrochemical energy storage device, comprising:

a deposition module (102) configured for depositing a ceramic layer(52) over a flexible substrate (111); and

15 an oxidation module (150) configured to subject the ceramic layer (52) to an oxidizing atmosphere at an elevated temperature.

12. The processing system according to claim 11, wherein the oxidation module (150) includes a gas assembly (151) configured to supply an oxidation gas and a heating assembly
20 (154) configured to elevate a temperature of at least one of the supplied oxidation gas, the flexible substrate and the ceramic layer.

13. The processing system according to claim 11 or 12, further comprising:

a substrate transport mechanism including a first roll (22) and a second roll (24), the
25 substrate transport mechanism being configured to transport the flexible substrate (111) along a transport path (P) from the first roll (22) to the second roll (24), the deposition module (102) and the oxidation module (150) being arranged along the transport path (P).

14. An oxidation chamber configured to oxidize a ceramic layer of a component of an electrochemical energy storage device, comprising:

a substrate transport mechanism including a first roll (222) and a second roll (224), the substrate transport mechanism being configured to transport a flexible substrate (111) along a transport path (P') from the first roll (222) to the second roll (224), a ceramic layer (52) being formed on the flexible substrate (111); and

an oxidation module (150) arranged at the transport path (P') between the first roll (222) and the second roll (224), the oxidation module (150) being configured to subject the ceramic layer (52) to an oxidizing atmosphere at an elevated temperature.

10

15. Oxidation chamber according to claim 14, further comprising:

a heating assembly (154) configured to elevate a temperature of at least one of the oxidation chamber (200), the oxidizing atmosphere, the flexible substrate (111) and the ceramic layer (52).

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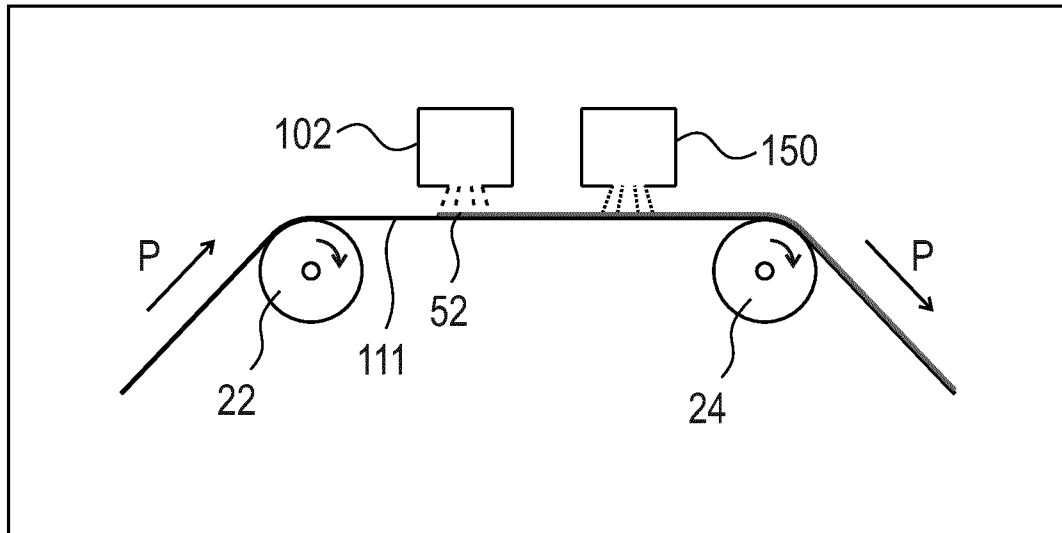
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Fig. 1

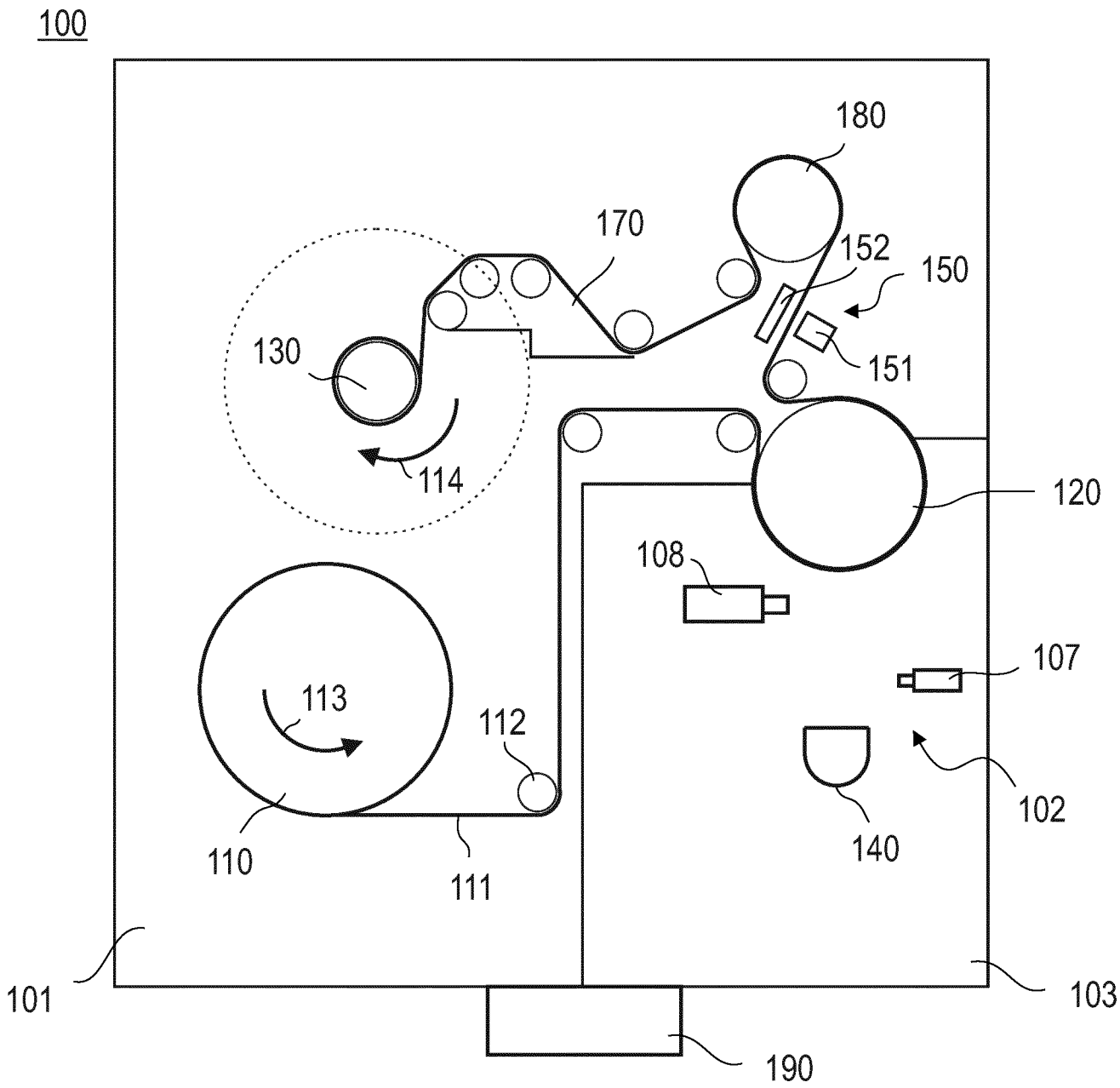
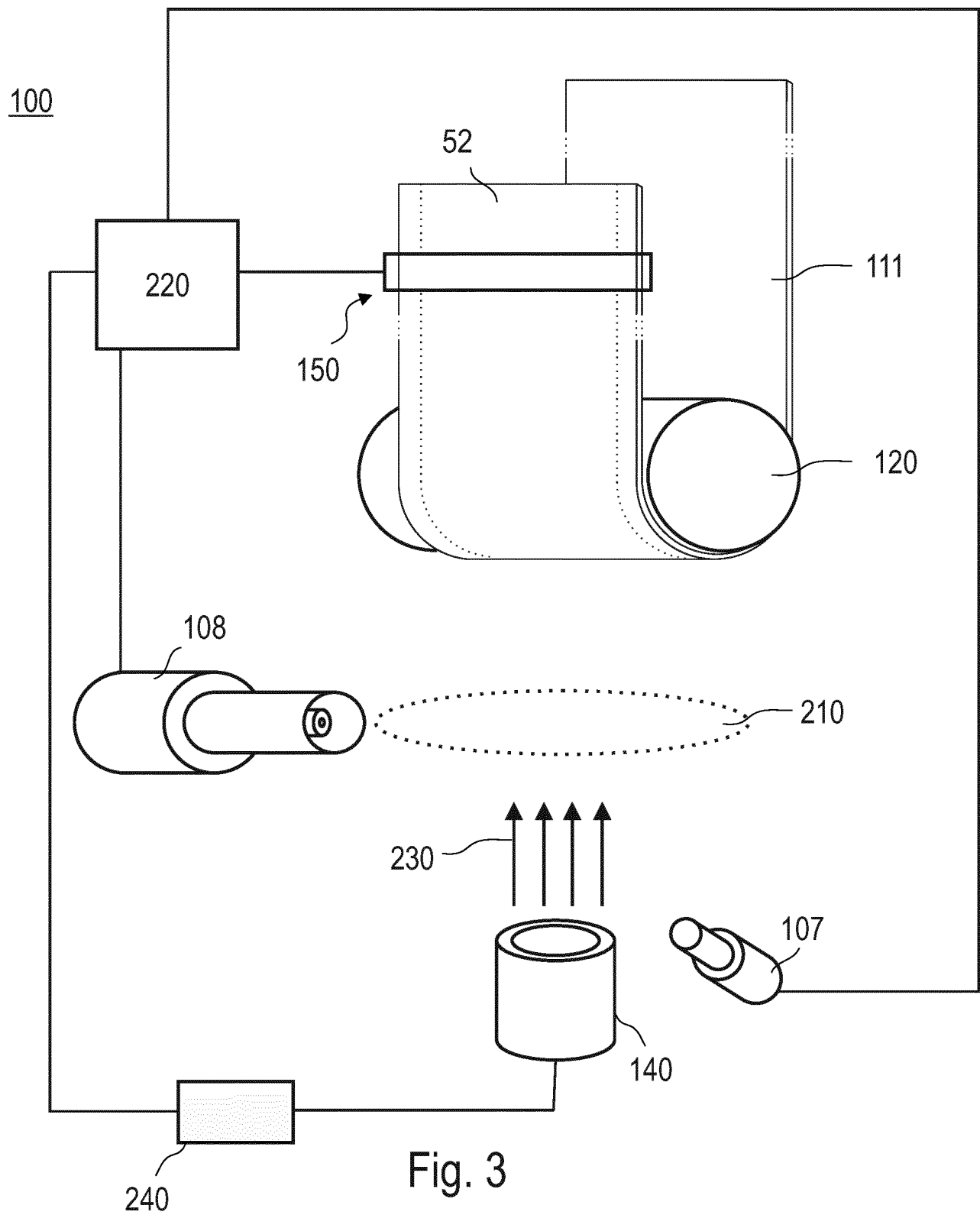


Fig. 2



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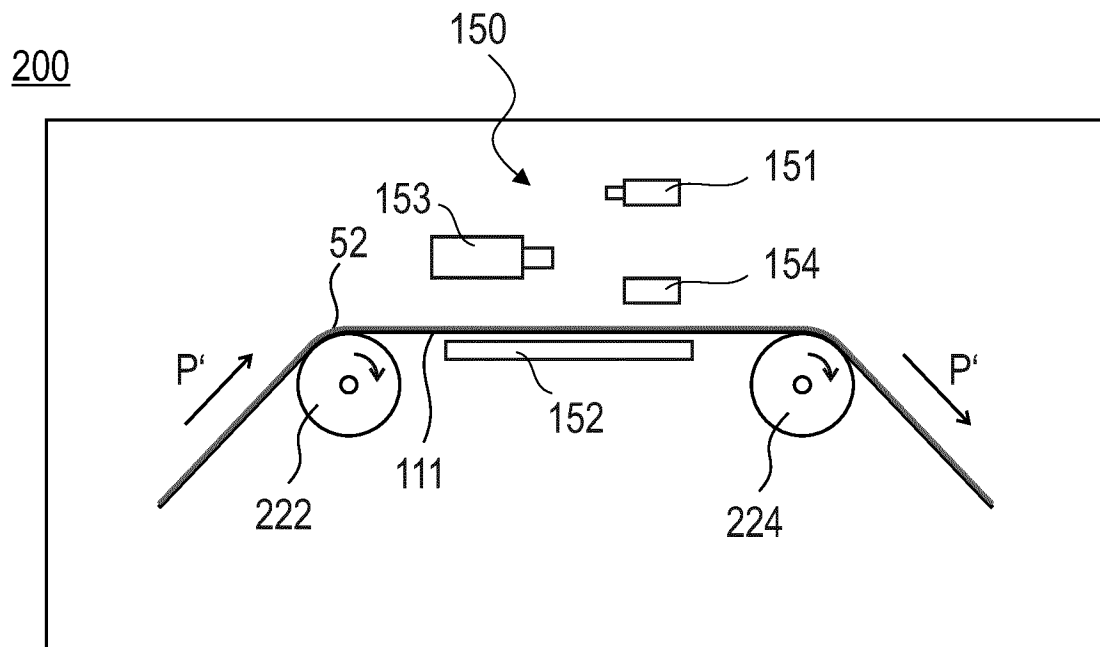


Fig. 4

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500

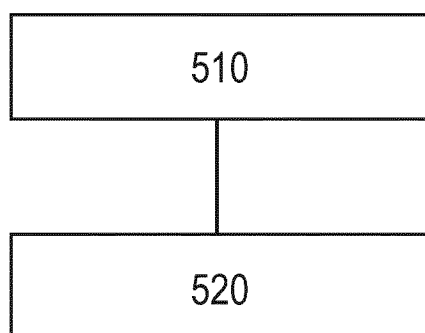


Fig. 5

300

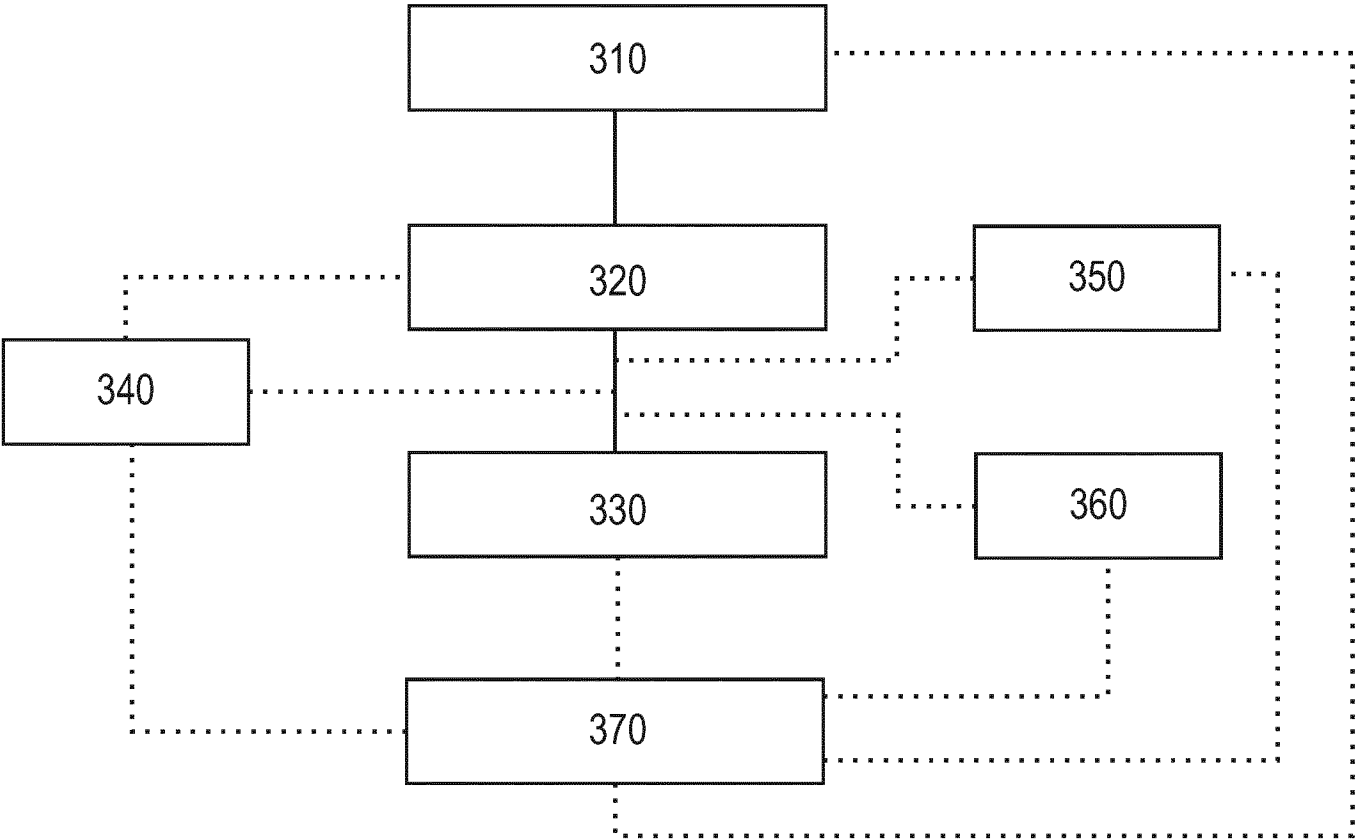


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/073776

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01M2/14 H01M2/16 H01M10/052
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)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2012/219841 A1 (BOLANDI HOOMAN [US] ET AL) 30 August 2012 (2012-08-30)	1-10
Y	paragraph [0035] - paragraph [0043] paragraph [0034] paragraph [0045] paragraph [0052] paragraph [0067] claims 17-18 paragraph [0006] paragraph [0014] - paragraph [0016] claims 14-17 ----- -/--	11-15

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

☒ See patent family annex.

* Special categories of cited documents :

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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Date of the actual completion of the international search

15 November 2017

Date of mailing of the international search report

23/11/2017

Name and mailing address of the ISA/

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Authorized officer

Tylus, Urszula

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/073776

C(Continuation). 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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Y	paragraph [0003] paragraph [0086] paragraph [0097] - paragraph [0099] paragraph [0008] paragraph [0027] - paragraph [0034] paragraph [0051] - paragraph [0053] paragraph [0099] paragraph [0071] - paragraph [0086]; figure 6	11-15
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International application No

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