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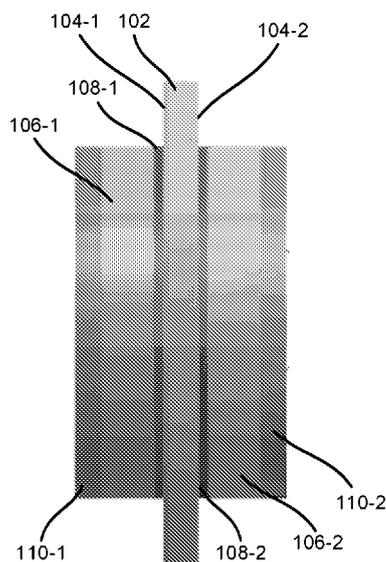


FIG. 1A

(57) **Abstract:** The present disclosure provides a solid-state battery 100, which includes: an electrolyte layer 102 wherein at least at a first surface, the electrolyte layer is a solid-state electrolyte; a first electrode layer 106-1 disposed on a first side of the electrolyte layer; a second electrode layer 106-2 disposed on a second side of the electrolyte layer; and a first interlayer 108-1 made of a first material, disposed between the electrolyte layer and the first electrode layer. The first electrode layer has low solubility in the first material, which facilitates reduced nucleation of the first electrode layer at interface of the first interlayer with the electrolyte layer due to excessive activation energy for nucleation, and the reduced nucleation enables reduced formation of dendrites at the first electrode layer.



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HIGH VOLTAGE AND HIGH ENERGY DENSITY BATTERY WITH INTERLAYERS

TECHNICAL FIELD

[0001] The present disclosure relates, in general, to the field of batteries. In particular, the present disclosure relates to batteries employing solid state electrolytes with improved stability and improved operation life at high operating voltages.

BACKGROUND

[0002] Background description includes information that can be useful in understanding the present invention. It is not an admission that any of the information provided herein is prior art or relevant to the presently claimed invention, or that any publication specifically or implicitly referenced is prior art.

[0003] Lithium ion batteries (LIBs) have been in prevalence for over two decades, particularly for portable electronics, electric vehicles and also grid storage. Conventional Li-ion battery technology employs electrolytes that have flammable organic solvents as key constituents. In addition, these electrolytes are thermodynamically unstable at voltages beyond 4 V, and stable, at voltages exceeding 4 V is essential for the development of high voltage and therefore, high energy density Li-ion batteries. Moreover, conventional lithium ion batteries use a graphite-based anode, which has a low theoretical specific capacity of about 372 mAh/g. due to which, conventional LIBs have limitations with respect to their energy and power density. Lithium metal anodes, with a theoretical specific capacity of 3860 mAh/g are ideal for the development of high energy density Li-ion batteries. Such storage devices could have applications such as in electric vehicles with long driving ranges. However, Lithium metal when used with liquid electrolytes tends to form filament like structures called dendrites due to uneven deposition of Li metal, and this can lead to short battery lifetime and also possible battery fires.

[0004] Efforts have been made in the related art to provide various solutions, and one of the solutions to the above-mentioned challenges can include a development of solid-state electrolytes that can mechanically suppress dendrite growth. Solid-state electrolytes are non-flammable, mechanically robust and (electro) chemically stable. Several solid-state electrolytes (inorganic and organic materials) have been proposed as candidate materials. However,

dendrite growth is experimentally observed in most of these solid-state electrolytes especially the ones with polycrystalline structure.

[0005] For example, garnet based Li-ion conductor $\text{Li}_7\text{La}_3\text{Zr}_2\text{O}_{12}$ (LLZO) and its doped variants have been extensively studied as potential candidates for utility in solid-state batteries. Garnet solid-state electrolytes have several favourable properties that are desired for solid-state Li-ion battery applications such as, 1) electrochemical stability against lithium and up to high voltages of ~6 V; 2) mechanical robustness; and 3) desired room temperature ionic conductivity of $\sim 10^{-3}$ S/cm. However, dendrite growth at current densities as low as $100 \mu\text{A}/\text{cm}^2$ has been observed.

[0006] The growth of dendrites can originate due to a gradual development of voids in the lithium layer at the interface between lithium and the solid-state electrolyte. At the edges of the voids, where lithium contacts the solid-state electrolyte, electric-field concentration and a resultant local current density enhancement could lead to the formation of lithium filaments (dendrites) either via electro-migration or by a process similar to the growth of filaments in resistive memories. As long as an interface between lithium and the solid-electrolyte exists, it is likely that such hotspots with high current density also exists, thereby leading to dendrite growth.

[0007] There is, therefore, a requirement in the art for a battery employing solid state electrolyte, with reduced dendrite growth at the interface of the electrode and the electrolyte.

OBJECTS OF THE PRESENT DISCLOSURE

[0008] A general object of the present disclosure is to provide a battery employing solid state electrolyte, with reduced dendrite growth at the interface of the electrodes and the electrolyte.

[0009] Another object of the present disclosure is to provide a battery employing solid state electrolyte, with stable operation at high voltages.

[0010] Another object of the present disclosure is to provide a battery employing solid state electrolyte, with improved operation life.

[0011] Another object of the present disclosure is to provide a method for manufacturing a battery employing solid state electrolyte, with reduced dendrite growth at the interface of the electrodes and the electrolyte.

SUMMARY

[0012] The present disclosure relates, in general, to the field of batteries. In particular, the present disclosure relates to batteries employing solid state electrolytes with improved stability and improved operation life at high operating voltages.

[0013] In an aspect, the present disclosure provides a battery, which includes: an electrolyte layer, which includes a first surface and a second surface, wherein at least at the first surface, the electrolyte layer is a solid-state electrolyte; a first electrode layer disposed on side of the first surface of the electrolyte layer; a second electrode layer disposed on side of the second surface of the electrolyte layer; and a first interlayer made of a first material, disposed between the first surface of the electrolyte layer and the first electrode layer such that the first interlayer is in contact with at least a portion of the electrolyte layer and the first electrode layer is in contact with at least a portion of the first interlayer. The first electrode layer has low solubility in the first material, which facilitates reduced nucleation of the first electrode layer at interface of the first interlayer with the electrolyte layer due to excessive activation energy for nucleation, and the reduced nucleation enables reduced formation of dendrites at the first electrode layer.

[0014] In an embodiment, the battery can be any of a lithium-ion battery, sodium-ion battery, potassium-ion battery, magnesium-ion battery, calcium-ion battery, and aluminium-ion battery.

[0015] In another embodiment, solubility of material of the first electrode in the first material can be less than 0.1 atomic percentage.

[0016] In another embodiment, the first material can have a melting point greater than 1700 °C.

[0017] In another embodiment, the first material can have an electronic conductivity greater than 0.1 mS/cm.

[0018] In another embodiment, the first interlayer can include any of a single layer of the first material, and one or more layers of one or more first materials.

[0019] In another embodiment, the first interlayer can have an average thickness in the range of 0.2 to 100 nm.

[0020] In another embodiment, the first material can be selected from a group comprising Molybdenum, Niobium, Tantalum, Tungsten, Rhenium, Chromium, Hafnium, Iridium, Osmium, Rhodium, Ruthenium, Zirconium; alloys and compounds of one or more of

Molybdenum, Niobium, Tantalum, Tungsten, Rhenium, Chromium, Hafnium, Iridium, Osmium, Rhodium, Ruthenium, Zirconium; and any combination thereof.

[0021] In another embodiment, the electrolyte layer can include a solid-solid state electrolyte at the first surface and the second surface. In another embodiment, the battery can include a second interlayer made of a second material, disposed between the second surface of the electrolyte layer and the second electrode layer such that the second interlayer is in contact with at least a portion of the electrolyte layer and the second electrode layer is in contact with at least a portion of the second interlayer. The second electrode layer has low solubility in the second material, which facilitates reduced nucleation of the second electrode layer at interface of second interlayer with the electrolyte layer due to excessive activation energy for nucleation, and the reduced nucleation enables reduced formation of dendrites at the second electrode layer.

[0022] In another embodiment, solubility of material of the second electrode in the first material can be less than 0.1 atomic percentage.

[0023] In another embodiment, the second material can have a melting point greater than 1700 °C.

[0024] In another embodiment, the second material can have an electronic conductivity greater than 0.1 mS/cm.

[0025] In another embodiment, the second interlayer can include any of a single layer of the second material, and one or more layers of one or more second materials.

[0026] In another embodiment, the second interlayer can have an average thickness in the range of 0.2 to 100 nm.

[0027] In another embodiment, the second material can be selected from a group comprising Molybdenum, Niobium, Tantalum, Tungsten, Rhenium, Chromium, Hafnium, Iridium, Osmium, Rhodium, Ruthenium, Zirconium; alloys and compounds of one or more of Molybdenum, Niobium, Tantalum, Tungsten, Rhenium, Chromium, Hafnium, Iridium, Osmium, Rhodium, Ruthenium, Zirconium; and any combination thereof.

[0028] In an aspect, the present disclosure provides a circuit, which includes the battery.

[0029] In another aspect, the present disclosure provides a battery, which includes: a solid-state electrolyte layer, which includes a first surface and a second surface; a first electrode layer disposed on side of the first surface of the electrolyte layer; a second electrode layer disposed on side of the second surface of the electrolyte layer; a first interlayer made of a first material, disposed between the first surface of the electrolyte layer and the first electrode layer

such that the first interlayer is in contact with at least a portion of the electrolyte layer and the first electrode layer is in contact with at least a portion of the first interlayer; and a second interlayer made of a second material, disposed between the second surface of the electrolyte layer and the second electrode layer such that the second interlayer is in contact with at least a portion of the electrolyte layer and the second electrode layer is in contact with at least a portion of the second interlayer. The first electrode layer and the second electrode layer has low solubility in the first material and the second material respectively, which facilitates reduced nucleation of the first electrode layer and the second electrode layer at interfaces of the first interlayer and second interlayer respectively with the electrolyte layer due to excessive activation energy for nucleation, and the reduced nucleation enables reduced formation of dendrites at the first electrode layer and the second electrode layer respectively.

[0030] Various objects, features, aspects, and advantages of the inventive subject matter will become more apparent from the following detailed description of preferred embodiments, along with the accompanying drawing figures in which like numerals represent like components.

BRIEF DESCRIPTION OF DRAWINGS

[0031] The accompanying drawings are included to provide a further understanding of the present invention and are incorporated in and constitute a part of this specification. The drawings illustrate exemplary embodiments of the present invention and, together with the description, serve to explain the principles of the present invention.

[0032] FIGs. 1A and 1B illustrate exemplary schematic representations of a battery, in accordance with embodiments of the present disclosure.

[0033] FIGs. 2A and 2B illustrate exemplary cross-sections of the proposed battery with a solid-state electrolyte layer and a hybrid electrolyte layer respectively, in accordance with an embodiment of the present disclosure.

[0034] FIGs. 3A and 3B illustrate exemplary cross-sections of the proposed battery in accordance with embodiments of the present disclosure.

[0035] FIG. 4A illustrates exemplary powder x-ray diffractograms of as synthesised LLZTO.

[0036] FIG. 4B illustrates an exemplary rendered model of the crystal structure of LLZTO.

[0037] FIGs. 4C and 4D illustrate exemplary scanning electron microscopy (SEM) images of the pellets of LLZTO.

[0038] FIGs. 5A and 5B illustrate an exemplary plot of overpotential vs interlayer thickness, and percentage polarization vs interlayer thickness respectively, at a fixed current density.

[0039] FIGs. 6A and 6B illustrate an exemplary Nyquist plot of electrochemical impedance spectroscopy performed on the battery without interlayer and the battery with the interlayer, respectively.

[0040] FIGs. 7A and 7B illustrate an exemplary Nyquist plot of electrochemical impedance spectroscopy performed on the battery without interlayer and the battery with Aluminium interlayer, respectively.

[0041] FIG. 8A – 8D illustrate exemplary plots of galvanostatic cycling at increasing current densities for batteries with tungsten interlayers at different temperatures, respectively.

[0042] FIG. 9 illustrates an exemplary comparison of critical current density vs interfacial impedance for batteries using tungsten interlayers and for batteries using aluminium interlayers, respectively.

[0043] FIG. 10 illustrates an exemplary representation of an interface of the lithium metal electrode and the solid LLZTO electrolyte.

[0044] FIG. 11A illustrates an exemplary optical microscopy image showing a central region without any interlayer deposition that is deliberately introduced so as to have a region of local current density hot spots.

[0045] FIG. 11B illustrates an exemplary optical microscopy image in the vicinity of the region without the interlayer showing a dark impression that is usually indicative of dendrite growth.

[0046] FIG. 11C illustrates an exemplary microscopy image where no such impressions are found on the opposite face of the solid electrolyte pellet.

[0047] FIG. 12 illustrates an exemplary comparison of critical current density for batteries with aluminium interlayers with batteries with tungsten interlayers at different temperatures.

[0048] FIG. 13 illustrates an exemplary cyclic voltammogram of a battery with a tungsten interlayer.

DETAILED DESCRIPTION

[0049] The following is a detailed description of embodiments of the disclosure depicted in the accompanying drawings. The embodiments are in such detail as to clearly communicate the disclosure. However, the amount of detail offered is not intended to limit the anticipated variations of embodiments; on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the present disclosure as defined by the appended claims.

[0050] If the specification states a component or feature “may”, “can”, “could”, or “might” be included or have a characteristic, that particular component or feature is not required to be included or have the characteristic.

[0051] As used in the description herein and throughout the claims that follow, the meaning of “a,” “an,” and “the” includes plural reference unless the context clearly dictates otherwise. Also, as used in the description herein, the meaning of “in” includes “in” and “on” unless the context clearly dictates otherwise.

[0052] Exemplary embodiments will now be described more fully hereinafter with reference to the accompanying drawings, in which exemplary embodiments are shown. These exemplary embodiments are provided only for illustrative purposes and so that this disclosure will be thorough and complete and will fully convey the scope of the invention to those of ordinary skill in the art. The invention disclosed may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Various modifications will be readily apparent to persons skilled in the art. The general principles defined herein can be applied to other embodiments and applications without departing from the spirit and scope of the invention. Moreover, all statements herein reciting embodiments of the invention, as well as specific examples thereof, are intended to encompass both structural and functional equivalents thereof. Additionally, it is intended that such equivalents include both currently known equivalents as well as equivalents developed in the future (i.e., any elements developed that perform the same function, regardless of structure). Also, the terminology and phraseology used is for the purpose of describing exemplary embodiments and should not be considered limiting. Thus, the present invention is to be accorded the widest scope encompassing numerous alternatives, modifications, and equivalents consistent with the principles and features disclosed. For purpose of clarity, details relating to technical material that is known in the technical fields related to the invention have not been described in detail so as not to unnecessarily obscure the present invention.

[0053] The use of any and all examples, or exemplary language (e.g., “such as”) provided with respect to certain embodiments herein is intended merely to better illuminate the invention and does not pose a limitation on the scope of the invention otherwise claimed. No language in the specification should be construed as indicating any non – claimed element essential to the practice of the invention.

[0054] The present disclosure relates, in general, to the field of batteries. In particular, the present disclosure relates to batteries employing solid state electrolytes with improved stability and improved operation life at high operating voltages.

[0055] In an aspect, the present disclosure provides a battery, which includes: an electrolyte layer, which includes a first surface and a second surface, wherein at least at the first surface, the electrolyte layer is a solid-state electrolyte; a first electrode layer disposed on side of the first surface of the electrolyte layer; a second electrode layer disposed on side of the second surface of the electrolyte layer; and a first interlayer made of a first material, disposed between the first surface of the electrolyte layer and the first electrode layer such that the first interlayer is in contact with at least a portion of the electrolyte layer and the first electrode layer is in contact with at least a portion of the first interlayer. The first electrode layer has low solubility in the first material, which facilitates reduced nucleation of the first electrode layer at interface of the first interlayer with the electrolyte layer due to excessive activation energy for nucleation, and the reduced nucleation enables reduced formation of dendrites at the first electrode layer.

[0056] In an embodiment, the battery can be any of a lithium-ion battery, sodium-ion battery, potassium-ion battery, magnesium-ion battery, calcium-ion battery, and aluminium-ion battery.

[0057] In another embodiment, solubility of material of the first electrode in the first material can be less than 0.1 atomic percentage.

[0058] In another embodiment, the first material can have a melting point greater than 1700 °C.

[0059] In another embodiment, the first material can have an electronic conductivity greater than 0.1 mS/cm.

[0060] In another embodiment, the first interlayer can include any of a single layer of the first material, and one or more layers of one or more first materials.

[0061] In another embodiment, the first interlayer can have an average thickness in the range of 0.2 to 100 nm.

[0062] In another embodiment, the first material can be selected from a group comprising Molybdenum, Niobium, Tantalum, Tungsten, Rhenium, Chromium, Hafnium, Iridium, Osmium, Rhodium, Ruthenium, Zirconium; alloys and compounds of one or more of Molybdenum, Niobium, Tantalum, Tungsten, Rhenium, Chromium, Hafnium, Iridium, Osmium, Rhodium, Ruthenium, Zirconium; and any combination thereof.

[0063] In another embodiment, the electrolyte layer can include a solid-solid state electrolyte at the first surface and the second surface. In another embodiment, the battery can include a second interlayer made of a second material, disposed between the second surface of the electrolyte layer and the second electrode layer such that the second interlayer is in contact with at least a portion of the electrolyte layer and the second electrode layer is in contact with at least a portion of the second interlayer. The second electrode layer has low solubility in the second material, which facilitates reduced nucleation of the second electrode layer at interface of second interlayer with the electrolyte layer due to excessive activation energy for nucleation, and the reduced nucleation enables reduced formation of dendrites at the second electrode layer.

[0064] In another embodiment, solubility of material of the second electrode in the first material can be less than 0.1 atomic percentage.

[0065] In another embodiment, the second material can have a melting point greater than 1700 °C.

[0066] In another embodiment, the second material can have an electronic conductivity greater than 0.1 mS/cm.

[0067] In another embodiment, the second interlayer can include any of a single layer of the second material, and one or more layers of one or more second materials.

[0068] In another embodiment, the second interlayer can have an average thickness in the range of 0.2 to 100 nm.

[0069] In another embodiment, the second material can be selected from a group comprising Molybdenum, Niobium, Tantalum, Tungsten, Rhenium, Chromium, Hafnium, Iridium, Osmium, Rhodium, Ruthenium, Zirconium; alloys and compounds of one or more of Molybdenum, Niobium, Tantalum, Tungsten, Rhenium, Chromium, Hafnium, Iridium, Osmium, Rhodium, Ruthenium, Zirconium; and any combination thereof.

[0070] In an aspect, the present disclosure provides a circuit, which includes the battery.

[0071] In another aspect, the present disclosure provides a battery, which includes: a solid-state electrolyte layer, which includes a first surface and a second surface; a first electrode

layer disposed on side of the first surface of the electrolyte layer; a second electrode layer disposed on side of the second surface of the electrolyte layer; a first interlayer made of a first material, disposed between the first surface of the electrolyte layer and the first electrode layer such that the first interlayer is in contact with at least a portion of the electrolyte layer and the first electrode layer is in contact with at least a portion of the first interlayer; and a second interlayer made of a second material, disposed between the second surface of the electrolyte layer and the second electrode layer such that the second interlayer is in contact with at least a portion of the electrolyte layer and the second electrode layer is in contact with at least a portion of the second interlayer. The first electrode layer and the second electrode layer has low solubility in the first material and the second material respectively, which facilitates reduced nucleation of the first electrode layer and the second electrode layer at interfaces of the first interlayer and second interlayer respectively with the electrolyte layer due to excessive activation energy for nucleation, and the reduced nucleation enables reduced formation of dendrites at the first electrode layer and the second electrode layer respectively.

[0072] FIGs. 1A and 1B illustrate exemplary schematic representations of a battery, in accordance with embodiments of the present disclosure. The battery 100 can include an electrolyte layer 102 with a first surface 104-1 and a second surface 104-2. The electrolyte layer 102, in an embodiment of the present disclosure can be a solid-state electrolyte, or a hybrid electrolyte including at least one part of solid-state electrolyte.

[0073] In another embodiment, a first electrode layer 106-1 can be disposed on a side of the first surface 104-1 and a second electrode layer 106-2 can be disposed on a side of the second surface 104-2.

[0074] In an embodiment, a first interlayer 108-1 can be disposed between the first surface 104-1 and the first electrode layer 106-1 such that the first interlayer 108-1 is in contact with at least a part of the first surface 104-1 and the first electrode layer 106-1 is in contact with at least a part of the first interlayer 108-1. In the case of a hybrid electrolyte layer case, the first surface 104-1 is on a side of the solid-electrolyte. In another embodiment, the first interlayer 108-1 can be a monolayer, or can have a multi-layered architecture. In the case of the multi-layered architecture, each of one or more layers of the multi-layer can be a same material or can be different materials.

[0075] In another embodiment, in the case of a solid-state electrolyte layer, a second interlayer 108-2 can be disposed between the second surface 104-2 and the second electrode layer 106-2 such that the second interlayer 108-2 is in contact with at least a part of the second

surface 104-2 and the second electrode layer 106-2 is in contact with at least a part of the second interlayer 108-2. In another embodiment, the second interlayer 108-2 can be a monolayer, or can have a multi-layered architecture. In the case of the multi-layered architecture, each of one or more layers of the multi-layer can be a same material or can be different materials.

[0076] It may be appreciated that the interlayers (108-1, 108-2) may be in contact with the entire respective surface (104-1, 104-2) of the electrolyte layer 102, and the electrode layers (106-1, 106-2) may be in contact with the entire respective interlayer (108-1, 108-2).

[0077] In another embodiment, current collectors (110-1, 110-2) may be provided at ends of the battery 100, in contact with the first electrode layer 106-1 and the second electrode layer 106-2.

[0078] In another embodiment, the interlayers (108-1, 108-2) can enhance current densities that can be drawn from the battery 100, while also mitigating battery failure due to dendrite growth. Further, the use of the interlayers (108-1, 108-2) can decrease electrode-electrolyte interfacial impedance, thereby improving energy conversion efficiency of the battery 100. Additionally, the interlayers (108-1, 108-2) can also enhance electrical connectivity between the electrolyte layer 102 respective electrode layers (106-1, 106-2).

[0079] FIGs. 2A and 2B illustrate exemplary cross-sections of the proposed battery with a solid-state electrolyte layer and a hybrid electrolyte layer respectively, in accordance with an embodiment of the present disclosure.

[0080] Referring to FIG. 2A, the cross-section illustrates a solid-state electrolyte layer 102, where two interlayers (108-1, 108-2) are disposed between the electrolyte layer 102 and the electrode layers (106-1, 106-2 respectively).

[0081] Referring to FIG. 2B, the cross-section illustrates a hybrid electrolyte layer 102, which includes a solid-state electrolyte 202, and a liquid electrolyte 204. An interlayer 108-1 is disposed between the solid-state electrolyte 202 and the first electrode layer 106-1. The second electrode layer 106-2 can be a stand-alone electrode which is electrically coupled with the solid-state electrolyte 202 through the liquid electrolyte.

[0082] In another embodiment, an intermediate electrolyte layer (not shown in figure) may be introduced at interface of the solid-state electrolyte 202 and the liquid electrolyte 204 such that the intermediate electrolyte layer is in contact with both the solid-state electrolyte 202 and the liquid electrolyte 204. The intermediate electrolyte layer can be partially or fully in contact with entire surface of the solid-state electrolyte 202 and the liquid electrolyte 204. In another embodiment, the intermediate electrolyte layer can be a monolayer, or can have a

multi-layered architecture. In the case of the multi-layered architecture, each of one or more layers of the multi-layer can be a same material or can be different materials.

[0083] FIGs. 3A and 3B illustrate exemplary cross-sections of the proposed battery with a solid-state electrolyte layer, in accordance with embodiments of the present disclosure.

[0084] Referring to FIG. 3A, the solid-state electrolyte 102 can have a dense central region, with interlayers (108-1, 108-2) disposed on the first and second surfaces respectively (104-1, 104-2) and with electrode layers (106-1, 106-2) disposed on the interlayers (108-1, 108-2).

[0085] Referring to FIG. 3B, in another embodiment, the solid-state electrolyte 102 can have a combination of dense and porous regions with a plurality of pores. The interlayers (108-1, 108-2) can be disposed on the respective surfaces (104-1, 104-2) forming a porous structure with the electrolyte 102. The electrode layers (106-1, 106-2) can be disposed on the interlayers (108-1, 108-2).

[0086] Referring again to FIGs. 1A and 1B, in an exemplary embodiment, the battery 100 can be a solid-state battery, and can be any of a lithium-ion battery, sodium-ion battery, potassium-ion battery, magnesium-ion battery, calcium-ion battery and aluminium-ion battery.

[0087] In an embodiment, the interlayers (108-1, 108-2) can have a thickness in the range of about 0.2 to 100 nm, which can be sandwiched between the electrolyte 102 and the respective electrode layers (106-1, 106-2) so as to achieve long battery cycle life and low interfacial impedance. The average thickness of the interlayers (108-1, 108-2) can be optimized to have enhanced resistance to dendrite growth while also yielding low interfacial impedance. Such optimizations may be done by, for example, tuning the thickness of the interlayer to be greater than or equal to the thickness of a single monolayer of the deposited material and less than or equal to 100 nm. The thickness of a single monolayer is defined as the smallest repeating unit of the crystalline form of the interlayer material. The lower limit for thickness for amorphous materials may be chosen to be 0.2 nm or to be equal to the root mean square roughness of the surfaces of the solid-state electrolyte.

[0088] In another embodiment, the interlayers (108-1, 108-2) may be disposed on the solid electrolyte 102 by techniques known in the art such as, without limitations, sputter deposition, thermal, e-beam or laser assisted evaporation, pulsed laser ablation deposition, atomic layer deposition, any related chemical or physical vapor deposition techniques and a combination thereof. The interlayers may also be deposited by electrode printing from inks comprising of the interlayer metals.

[0089] In an exemplary embodiment, the interlayers (108-1, 108-2) can be chosen from electron-conducting materials with a high melting temperature and a sparingly low solubility for battery electrode materials. The interlayers (108-1, 108-2) may be chosen from materials with an electronic conductivity of about 0.1 mS/cm and greater; a melting temperature of about 1700 °C and greater; and a solubility of about 0.1 atomic percent and lower with respect to the electrode layers.

[0090] In another exemplary embodiment, the material(s) for the interlayers may be advantageously chosen from a group consisting of Molybdenum, Niobium, Tantalum, Tungsten, Rhenium, Chromium, Hafnium, Iridium, Osmium, Rhodium, Ruthenium, Zirconium, alloys, and compounds thereof. The interlayer materials may also be chosen from any or a combination of metal oxides, metal carbides, metal borides, metal nitrides and refractory metal alloys.

[0091] In an exemplary embodiment, solubility of lithium or sodium or potassium or magnesium or calcium or aluminium in at least one of the interlayers can be in a range of 1 ppb to 10000 ppm at a temperature of 25 degrees centigrade and at a pressure of 1 atmosphere, in any of the battery anode or cathode materials. In an exemplary embodiment, solubility of alloys of lithium or sodium or potassium or magnesium or calcium or aluminium in at least one of the interlayers can be greater than 1 ppb but less than 10000 ppm at a temperature of 25 degrees centigrade, and at a pressure of 1 atmosphere. Table 1 below illustrates an exemplary table of solubility of tungsten (W) in lithium, sodium, potassium, magnesium, and aluminium.

Alkali metal	Temperature (°C)	Tungsten Concentration (wt. ppm)	Remarks
Lithium	< 1000	3	-
Sodium	-	-	Low solubility predicted
Potassium	< 1000	50	-
Magnesium	-	-	No reaction between Mg and W
Aluminium	< 660	>1 ppb	Alloying takes place when in molten form

Table 1: Solubility of Tungsten (W) in Alkali and alkaline earth metals

[0092] Table 2 illustrates an exemplary table of solubility of molybdenum in lithium, sodium, potassium, magnesium, and aluminium.

Alkali metal	Temperature (°C)	Molybdenum Concentration (wt. ppm)	Remarks
Lithium	< 1000	>1 ppb	Low solubility predicted
Sodium	-	-	-
Potassium	<778.85	>1 ppb	Low solubility predicted
Magnesium	-	-	No reaction between Mg and Mo
Aluminium	<660	>1 ppb	Alloying takes place when in molten form

Table 2: Solubility of Molybdenum in Alkali and alkaline earth metals

[0093] The data on lithium solubility in tungsten (W) or molybdenum (Mo) could not be found. The data for solubility of these metals in lithium is taken as an indirect indicator for possible low solubility of lithium in the refractory metals.

[0094] In an embodiment, the thickness of the electrolyte 102 may be advantageously chosen to be in the range of about 1 – 1000 μm so as to have a sufficiently high mechanical strength and sufficiently low ionic resistance. The structure of the solid-state electrolyte layer may be advantageously designed to comprise solely of a dense solid-electrolyte region or have at least one side of the dense solid-state electrolyte in contact with a porous solid-state electrolyte in order to achieve high current density.

[0095] In another embodiment, the electrolyte 102 can have its surfaces (104-1, 104-2) advantageously modified to have good adhesion with the interlayers (108-1, 1-8-2) by one or more surface modification or improvement methods such as, without limitations surface polishing; surface treatments to improve adhesion or remove contaminants; other surface modification techniques such as disposing a thin layer comprising one or more organic or inorganic materials other than the interlayer itself for improved bonding or adhesion between the interlayer and the solid electrolyte; and a combination thereof.

[0096] In another exemplary embodiment, the solid-state electrolyte can be chosen from a sodium-ion conducting material, a potassium-ion conducting material, a magnesium-ion conducting material, a calcium-ion conducting material, and an aluminium-ion conducting material.

[0097] In another exemplary embodiment, the material(s) for the solid-state electrolyte 104 can be chosen from any or a combination of inorganic Li-ion conducting single or polycrystalline materials, and organic polymer electrolytes. Examples of such electrolytes can include, without limitations, Li_3N , β -Alumina, LISICON (Lithium superionic conductors) such as $(\text{Li}_{1.3}\text{Al}_{0.3}\text{Ti}_{1.7}(\text{PO}_3)_4)$; LiPON ($\text{Li}_{2.88}\text{PO}_{3.86}\text{N}_{0.14}$) and its variants; LGPS ($\text{Li}_{10}\text{GeP}_2\text{S}_{12}$) and its variants; LLZO garnet ($\text{Li}_7\text{La}_3\text{Zr}_2\text{O}_{12}$) and its variants; and combinations thereof.

[0098] In another exemplary embodiment, electrode materials can be advantageously chosen from any known electrode materials for any of lithium-ion battery, sodium-ion battery, potassium-ion battery, magnesium-ion battery, calcium-ion battery and aluminium-ion battery such as lithium, sodium, potassium, magnesium, calcium, aluminium, and alloys or compounds thereof.

[0099] In an illustration of the embodiments of the present disclosure, a lithium ion battery is considered with the interlayer chosen from a class of refractory metals with low solubility for lithium (such as tungsten and molybdenum). The solid-state electrolyte for the exemplary battery is chosen from a class of tantalum doped lithium ion conducting garnet materials with a fixed room temperature ionic conductivity of about 0.6 mS/cm such as LLZTO ($\text{Li}_{6.5}\text{La}_3\text{Zr}_{1.5}\text{Ta}_{0.5}\text{O}_{12}$).

[0100] FIG. 4A illustrates exemplary powder x-ray diffractograms of as synthesised LLZTO. It can be seen that the pattern (402) agrees with international centre for diffraction data (ICDD) standard diffractogram pattern (404) for a cubic phase of LLZTO.

[0101] FIG. 4B illustrates an exemplary rendered model of the crystal structure of LLZTO.

[0102] In another embodiment, 12 mm diameter pellets of the solid-state electrolyte with a fixed thickness of about 1 mm are prepared using powder compaction and sintering techniques known in the art.

[0103] FIGs. 4C and 4D illustrate exemplary scanning electron microscopy (SEM) images of the pellets of LLZTO.

[0104] In another embodiment, symmetric batteries with the interlayers disposed on the two surfaces of a centrally located solid-state electrolyte layer with lithium disposed on the interlayers are prepared.

[0105] It may be appreciated by persons skilled in the art that the described battery and the materials used are illustrations, and that the embodiments of the present disclosure may be realised using other materials and architectures, which form part of the scope of the present disclosure.

[0106] In a first example, the two interlayers are chosen to be tungsten and have nominally identical thicknesses of either 30 nm or 60 nm or 90 nm.

[0107] FIGs. 5A and 5B illustrate an exemplary plot of overpotential vs interlayer thickness, and percentage polarization vs interlayer thickness respectively, at a current density of 100 $\mu\text{A}/\text{cm}^2$. Galvanostatic plating and stripping of lithium performed on these symmetric batteries show that the interfacial impedance and the voltage polarization is the largest for the cell with the thickest interlayer. In this instance, lowest overpotential for lithium plating and the lowest percentage polarization can be noted for solid state symmetric cells with 30 nm tungsten as an interlayer. Such interlayer thickness optimizations may be performed for identifying the optimal thickness for any electrode-interlayer-electrolyte combinations.

[0108] In another embodiment, sputtering is used to deposit a 30 nm tungsten layer on the two surfaces of a 1 mm thick, 12 mm diameter pellet of LLZTO garnet. This is followed by pressing a fresh piece of lithium metal on both sides of the pellet. Stainless steel plates are then placed on both sides of the pellet for use as current collectors. The entire assembly is then heated on a hot plate at about 300 °C for about 24 hours. The assembly is then cooled and transferred to an electrochemical measurement apparatus.

[0109] In a second example, symmetric batteries can be assembled without the interlayers. However, the lithium and rest of the cell construction is maintained similar to the first example.

[0110] Electrochemical impedance spectroscopy are performed on the batteries of the two examples.

[0111] FIGs. 6A and 6B illustrate an exemplary Nyquist plot of electrochemical impedance spectroscopy performed on the battery without interlayer and the battery with the interlayer, respectively. The Interfacial impedance of the battery without the tungsten interlayer is about 6500 ohm-cm². The interfacial impedance drops to about 500 ohm-cm² upon the

introduction of the interlayer. In this instance, the battery with the interlayer has an interfacial impedance that is about an order of magnitude lower than the battery without the interlayer.

[0112] In a third example, sputtering is used to dispose a 50 nm aluminium interlayer on the two surfaces of a 1 mm thick, 12 mm diameter pellet of LLZTO. The pressing of lithium and rest of the cell construction was maintained to be similar to the first example. Electrochemical impedance spectroscopy is performed on the battery of the third example.

[0113] FIGs. 7A and 7B illustrate an exemplary Nyquist plot of electrochemical impedance spectroscopy performed on the battery without interlayer and the battery with Aluminium interlayer, respectively. The Interfacial impedance of the battery without the tungsten interlayer is about 6500 ohm-cm². The interfacial impedance drops to about 500 ohm-cm² upon the introduction of the interlayer. In this instance, the battery with the interlayer has an interfacial impedance that is about an order of magnitude lower than the battery without the interlayer.

[0114] FIG. 8A – 8D illustrate exemplary plots of galvanostatic cycling at increasing current densities for batteries with tungsten interlayers at temperatures of 25 °C, 40 °C, 60 °C and 70 °C, respectively. Each constant current density step consists of 5 sets of a charge and a discharge of 300 seconds each. The potential increases linearly with increasing current density, as expected from Ohm's law. The current density at which an unexpected abrupt drop in potential is observed is termed as the critical current density for dendrite growth. This is also the current density at which the battery is assumed to be electrically shorted. The current densities corresponding to this shorting at the four different temperatures are given in FIGs. 7A – 7D.

[0115] FIG. 9 illustrates an exemplary comparison of critical current density vs interfacial impedance for batteries using tungsten interlayers and for batteries using aluminium interlayers, respectively. It can be seen that batteries with tungsten interlayers can withstand higher current densities.

[0116] FIG. 10 illustrates an exemplary representation of an interface of the lithium metal electrode and the solid LLZTO electrolyte. It may be proposed that locally inhomogeneous deposition of lithium at the interface between the lithium layer and the solid-state electrolyte leads to local hot spots (microscopic regions with current density higher than the average current density) that drive lithium dendrite growth. Further, the layers with a higher melting temperature and lower solubility for lithium minimize lithium creep into the solid-state electrolyte and therefore minimize lithium dendrite growth.

[0117] FIG. 11A illustrates an exemplary optical microscopy image showing a central region without any interlayer deposition that is deliberately introduced so as to have a region of local current density hot spots.

[0118] FIG. 11B illustrates an exemplary optical microscopy image in the vicinity of the region without the interlayer showing a dark impression that is usually indicative of dendrite growth.

[0119] FIG. 11C illustrates an exemplary microscopy image where no such impressions are found on the opposite face of the solid electrolyte pellet.

[0120] Referring to FIGs. 11A – 11C, in a fourth example, a small region (with an area of 2-5% of the total area) of high interfacial resistance is introduced while the rest of the area prepared similar to the first example. Upon performing galvanostatic cycling, these cells leave impressions of dendrite growth within the region with high interfacial resistance, but no such impression on regions with interlayers. These are regions where a high number density of hotspots are expected. It can hence be shown that the presence of hotspots accentuate lithium dendrite growth.

[0121] FIG. 12 illustrates an exemplary comparison of critical current density for batteries with aluminium interlayers with batteries with tungsten interlayers at four temperatures of 25 °C, 40 °C, 60 °C and 70 °C. It can be seen that the batteries with tungsten interlayers perform better at higher temperatures.

[0122] FIG. 13 illustrates an exemplary cyclic voltammogram of a battery with a tungsten interlayer. It can be seen that the battery displays an electrochemical stability up to 6 V, positioning such a battery as a candidate for use in high voltage solid state batteries.

[0123] Thus, the present disclosure provides a battery which includes interlayers between the solid-state electrolyte and the electrode of the battery. The interlayers may be chosen from materials which are electron conducting while also having a high melting temperature and a sparingly low solubility for battery electrode materials. The interlayers improve the deposition characteristics of, for example, metallic anodes in solid state batteries. The interlayers may be chosen to have low solubility for metallic anodes such as, for example, lithium or sodium or potassium or magnesium or calcium or aluminium or alloys that comprise at least one of the said anodes as constituent elements. For example, without loss of generality, the interlayers could comprise of refractory metals such as tungsten or molybdenum or tantalum or rhenium or niobium or refractory alloys or refractory compounds that comprise at least one of the said refractory metals as constituent elements. The interlayers may also be chosen from metal

borides or carbides or nitrides or oxides. The battery further includes of battery electrode materials disposed on the interlayers such that the battery electrode materials are in partial or complete contact with the interlayer on such surfaces where the interlayer has been disposed on the solid-state electrolyte. These interlayers may be advantageously used to enhance current densities that can be drawn from a battery while also mitigating battery failure via known battery failure routes such as, for example, through dendrite growth. Furthermore, such interlayers may decrease electrode-electrolyte interfacial impedance, thereby improving the battery's energy conversion efficiency.

[0124] It should be apparent to those skilled in the art that many more modifications besides those already described are possible without departing from the inventive concepts herein. The inventive patent matter, therefore, is not to be restricted except in the spirit of the appended claims. Moreover, in interpreting both the specification and the claims, all terms should be interpreted in the broadest possible manner consistent with the context. In particular, the terms "includes" and "including" should be interpreted as referring to elements, components, or steps in a non-exclusive manner, indicating that the referenced elements, components, or steps can be present, or utilized, or combined with other elements, components, or steps that are not expressly referenced. Where the specification claims refer to at least one of something selected from the group consisting of A, B, C ...and N, the text should be interpreted as requiring only one element from the group, not A plus N, or B plus N, etc. The foregoing description of the specific embodiments will so fully reveal the general nature of the embodiments herein that others can, by applying current knowledge, readily modify and/or adapt for various applications such specific embodiments without departing from the generic concept, and, therefore, such adaptations and modifications should and are intended to be comprehended within the meaning and range of equivalents of the disclosed embodiments. It is to be understood that the phraseology or terminology employed herein is for the purpose of description and not of limitation. Therefore, while the embodiments herein have been described in terms of preferred embodiments, those skilled in the art will recognize that the embodiments herein can be practised with modification within the spirit and scope of the appended claims.

[0125] While the foregoing describes various embodiments of the invention, other and further embodiments of the invention can be devised without departing from the basic scope thereof. The scope of the invention is determined by the claims that follow. The invention is not limited to the described embodiments, versions or examples, which are included to enable

a person having ordinary skill in the art to make and use the invention when combined with information and knowledge available to the person having ordinary skill in the art.

ADVANTAGES OF THE PRESENT DISCLOSURE

[0126] The present disclosure provides a battery employing a solid-state electrolyte, with reduced dendrite growth at the interface of the electrodes and the electrolyte.

[0127] The present disclosure provides a battery employing a solid-state electrolyte, with stable operation at high voltages.

[0128] The present disclosure provides a battery employing a solid-state electrolyte, with improved operation life.

[0129] The present disclosure provides a method for manufacturing a battery employing a solid-state electrolyte, with reduced dendrite growth at the interface of the electrodes and the electrolyte.

We Claim:

1. A battery (100) comprising:

an electrolyte layer (102) comprising a first surface (104-1) and a second surface (104-2), wherein at least at the first surface (104-1), the electrolyte layer is a solid-state electrolyte (202);

a first electrode layer (106-1) disposed on side of the first surface (104-1) of the electrolyte layer (102);

a second electrode layer (106-2) disposed on side of the second surface (104-2) of the electrolyte layer (102); and

a first interlayer (108-1) made of a first material, disposed between the first surface (104-1) of the electrolyte layer (102) and the first electrode layer (106-1) such that the first interlayer (108-1) is in contact with at least a portion of the electrolyte layer (102) and the first electrode layer (106-1) is in contact with at least a portion of the first interlayer (108-1),

wherein the first electrode layer (106-1) has low solubility in the first material, which facilitates reduced nucleation of the first electrode layer (106-1) at interface of the first interlayer (108-1) with the electrolyte layer (102) due to excessive activation energy for nucleation, and

wherein reduced nucleation enables reduced formation of dendrites at the first electrode layer (106-1).

2. The battery as claimed in claim 1, wherein the battery (100) is any of a lithium-ion battery, sodium-ion battery, potassium-ion battery, magnesium-ion battery, calcium-ion battery, and aluminium-ion battery.
3. The battery as claimed in claim 1, wherein solubility of material of the first electrode (106-1) in the first material is less than 0.1 atomic percentage.
4. The battery as claimed in claim 1, wherein the first material has a melting point greater than 1700 °C.
5. The battery as claimed in claim 1, wherein first material has an electronic conductivity greater than 0.1 mS/cm.
6. The battery as claimed in claim 1, wherein the first interlayer comprises any of a single layer of the first material, and one or more layers of one or more first materials.

7. The battery as claimed in claim 1, wherein the first interlayer (108-1) has an average thickness in the range of 0.2 to 100 nm.
8. The battery as claimed in claim 1, wherein the first material is selected from a group comprising Molybdenum, Niobium, Tantalum, Tungsten, Rhenium, Chromium, Hafnium, Iridium, Osmium, Rhodium, Ruthenium, Zirconium; alloys and compounds of one or more of Molybdenum, Niobium, Tantalum, Tungsten, Rhenium, Chromium, Hafnium, Iridium, Osmium, Rhodium, Ruthenium, Zirconium; and any combination thereof.
9. The battery as claimed in claim 1, wherein the electrolyte layer (102) comprises a solid-solid state electrolyte (202) at the first surface (104-1) and the second surface (104-2).
10. The battery as claimed in claim 1, wherein the battery comprises a second interlayer (108-2) made of a second material, disposed between the second surface (104-2) of the electrolyte layer (102) and the second electrode layer (106-2) such that the second interlayer (108-2) is in contact with at least a portion of the electrolyte layer (102) and the second electrode layer (106-2) is in contact with at least a portion of the second interlayer (108-2),
wherein the second electrode layer (106-2) has low solubility in the second material, which facilitates reduced nucleation of the second electrode layer (106-2) at interface of second interlayer (108-2) with the electrolyte layer (102) due to excessive activation energy for nucleation, and
wherein reduced nucleation enables reduced formation of dendrites at the second electrode layer (106-2).
11. The battery as claimed in claim 10, wherein solubility of material of the second electrode (106-2) in the second material is less than 0.1 atomic percentage.
12. The battery as claimed in claim 10, wherein the second material has a melting point greater than 1700 °C.
13. The battery as claimed in claim 10, wherein second material has an electronic conductivity greater than 0.1 mS/cm.
14. The battery as claimed in claim 10, wherein the second interlayer comprises any of a single layer of the second material and one or more layers of one or more second materials.
15. The battery as claimed in claim 10, wherein the second interlayer (108-1) has an average thickness in the range of 0.2 to 100 nm.

16. The battery as claimed in claim 10, wherein the second material is selected from a group comprising Molybdenum, Niobium, Tantalum, Tungsten, Rhenium, Chromium, Hafnium, Iridium, Osmium, Rhodium, Ruthenium, Zirconium; alloys and compounds of one or more of Molybdenum, Niobium, Tantalum, Tungsten, Rhenium, Chromium, Hafnium, Iridium, Osmium, Rhodium, Ruthenium, Zirconium; and any combination thereof.
17. A circuit comprising a battery of claim 1.
18. A battery (100) comprising:
 - a solid-state electrolyte layer (102) comprising a first surface (104-1) and a second surface (104-2);
 - a first electrode layer (106-1) disposed on side of the first surface (104-1) of the electrolyte layer (102);
 - a second electrode layer (106-2) disposed on side of the second surface (104-2) of the electrolyte layer (102);
 - a first interlayer (108-1) made of a first material, disposed between the first surface (104-1) of the electrolyte layer (102) and the first electrode layer (106-1) such that the first interlayer (108-1) is in contact with at least a portion of the electrolyte layer (102) and the first electrode layer (106-1) is in contact with at least a portion of the first interlayer (108-1); and
 - a second interlayer (108-2) made of a second material, disposed between the second surface (104-2) of the electrolyte layer (102) and the second electrode layer (106-2) such that the second interlayer (108-2) is in contact with at least a portion of the electrolyte layer (102) and the second electrode layer (106-2) is in contact with at least a portion of the second interlayer (108-2),wherein the first electrode layer (106-1) and the second electrode layer (106-2) has low solubility in the first material and the second material respectively, which facilitates reduced nucleation of the first electrode layer (106-1) and the second electrode layer (106-2) at interfaces of the first interlayer (108-1) and second interlayer (108-2) respectively with the electrolyte layer (102) due to excessive activation energy for nucleation, and

wherein reduced nucleation enables reduced formation of dendrites at the first electrode layer (106-1) and the second electrode layer (106-2) respectively.

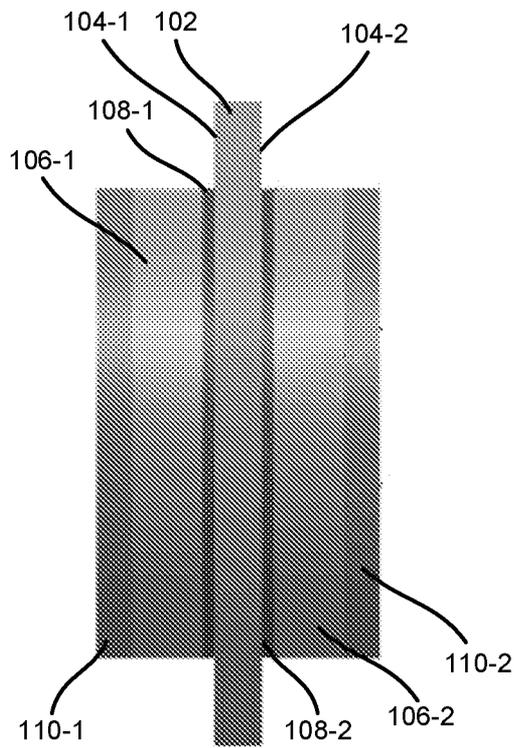


FIG. 1A

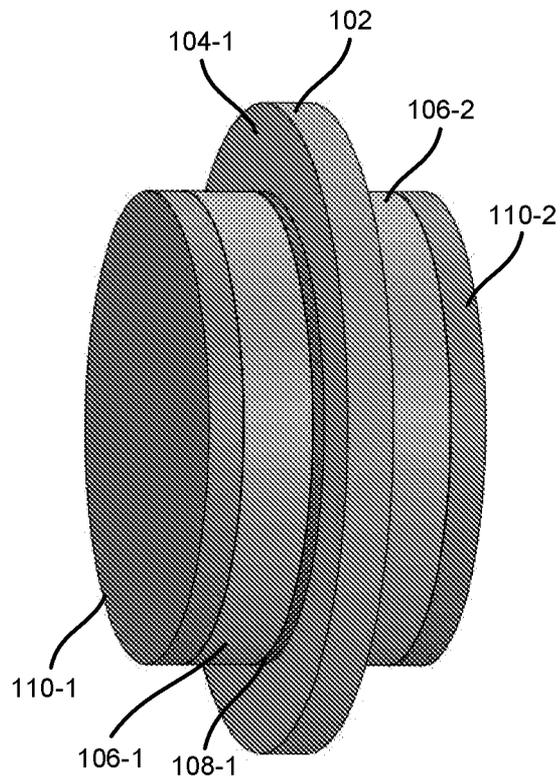


FIG. 1B

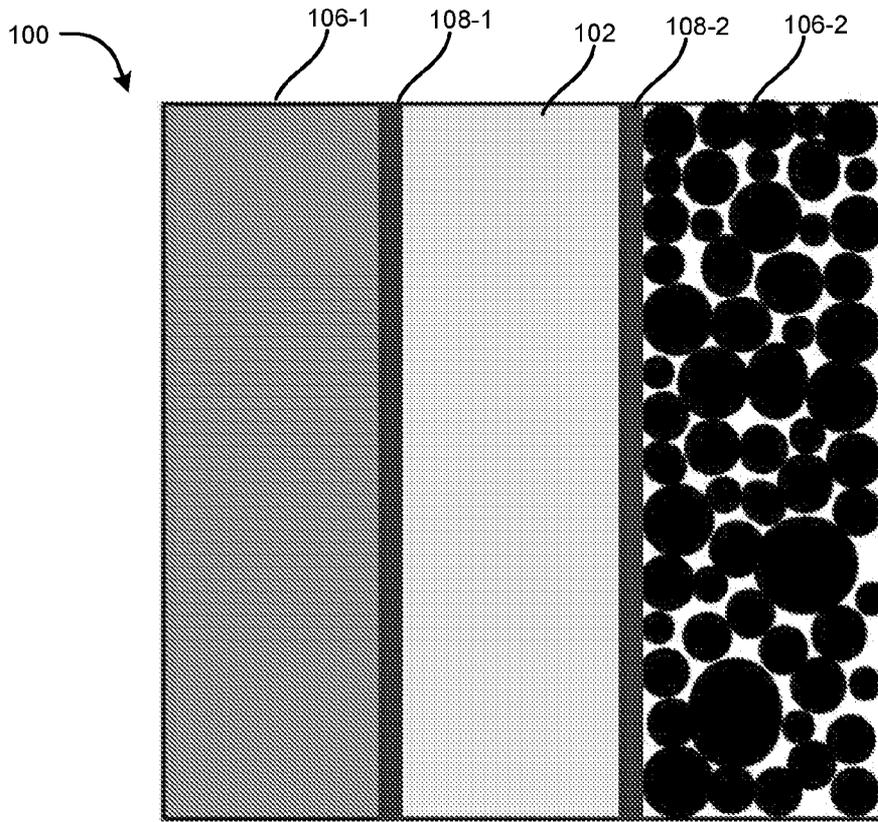


FIG. 2A

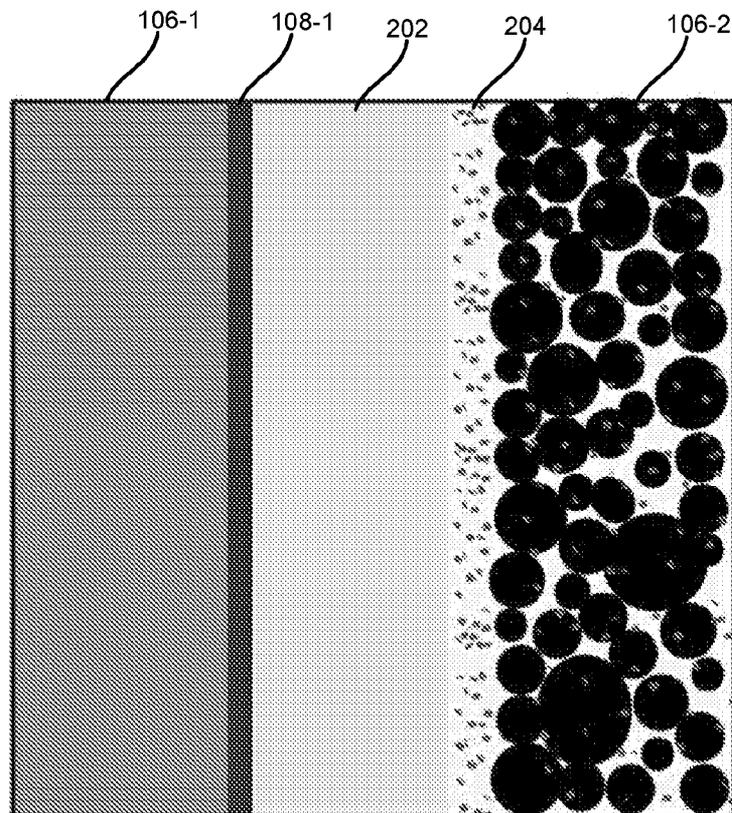


FIG. 2B

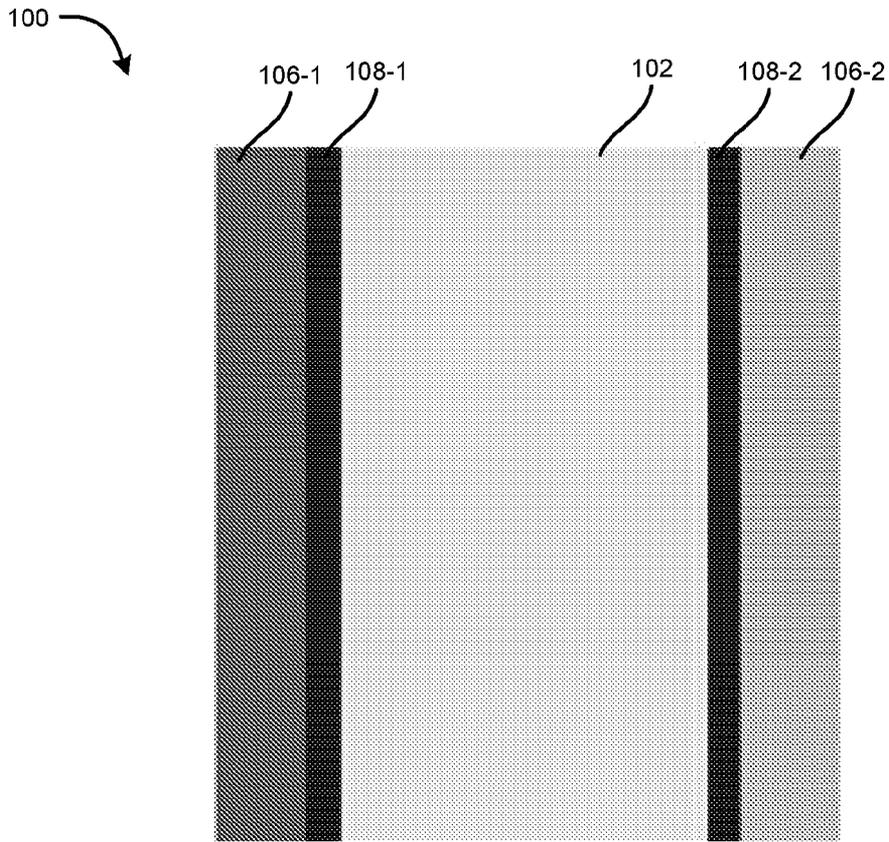


FIG. 3A

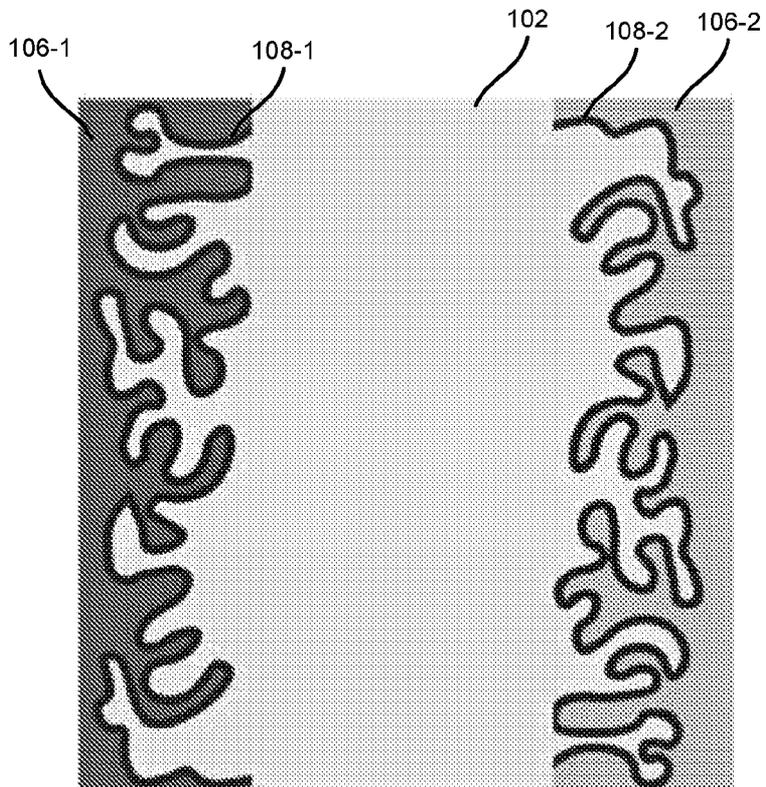


FIG. 3B

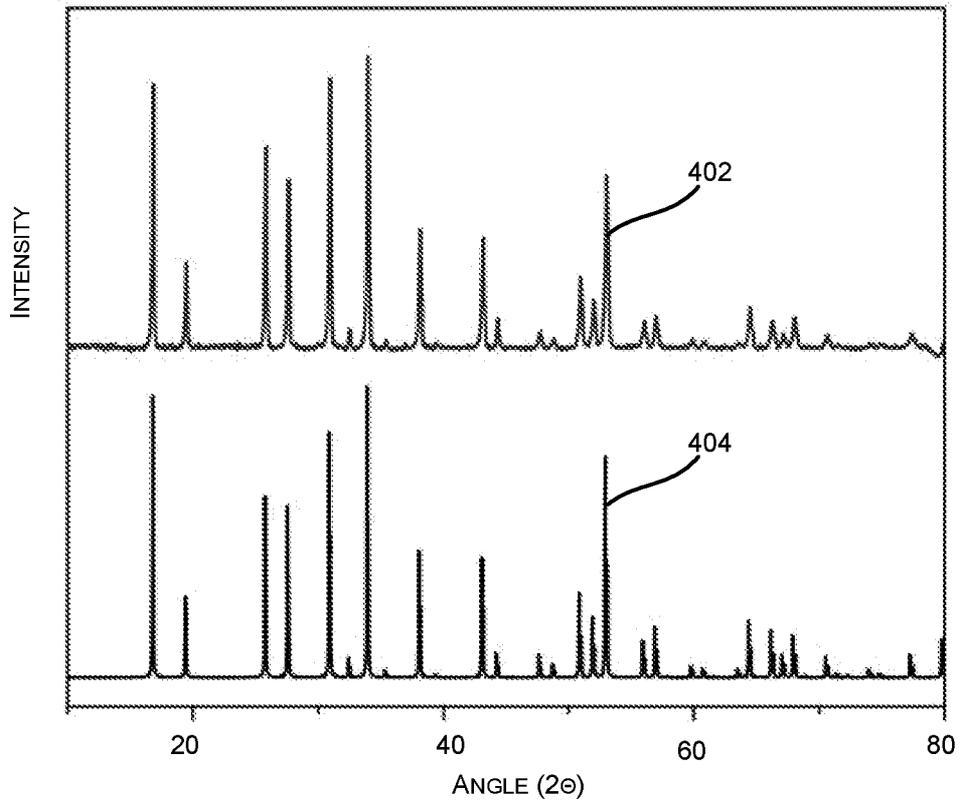


FIG. 4A

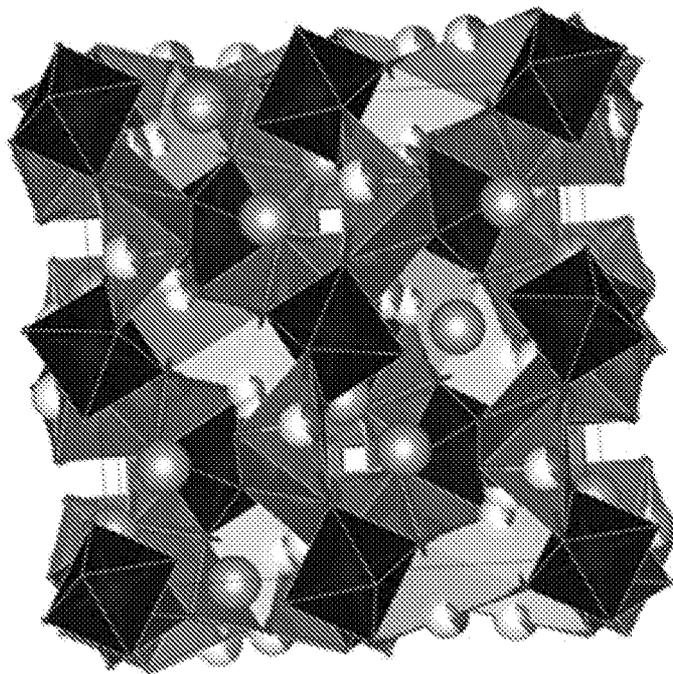


FIG. 4B

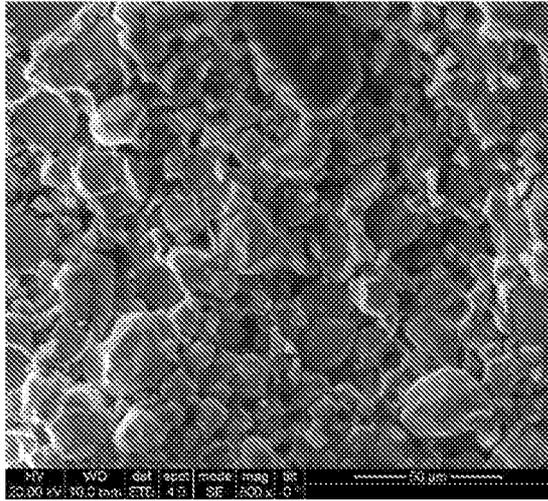


FIG. 4C

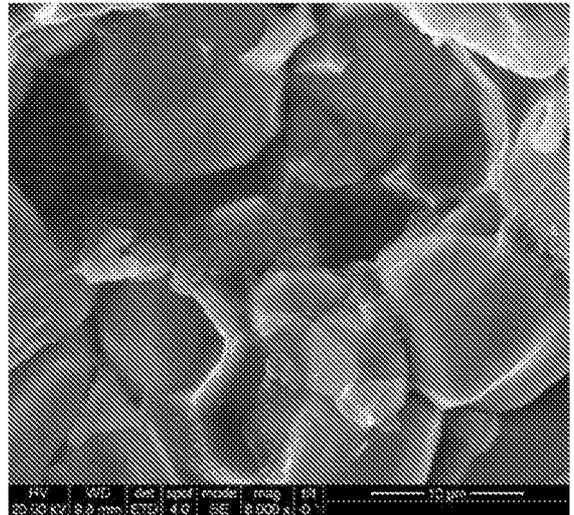


FIG. 4D

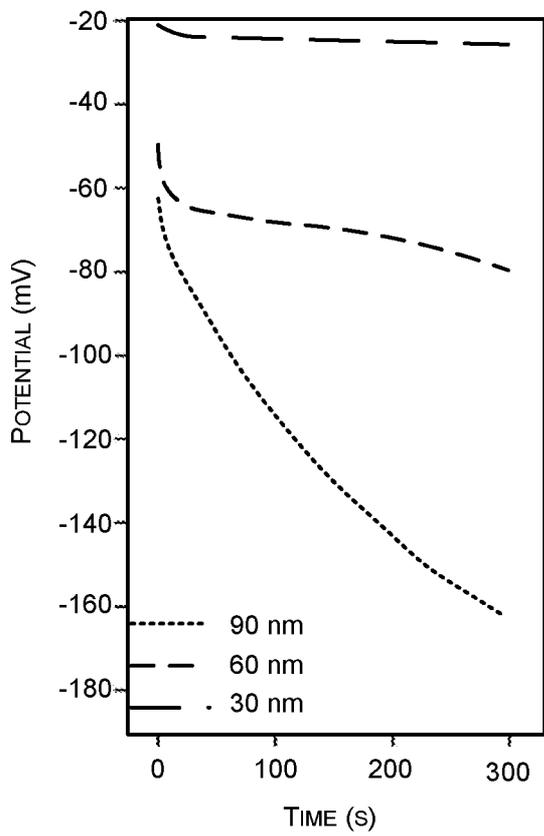


FIG. 5A

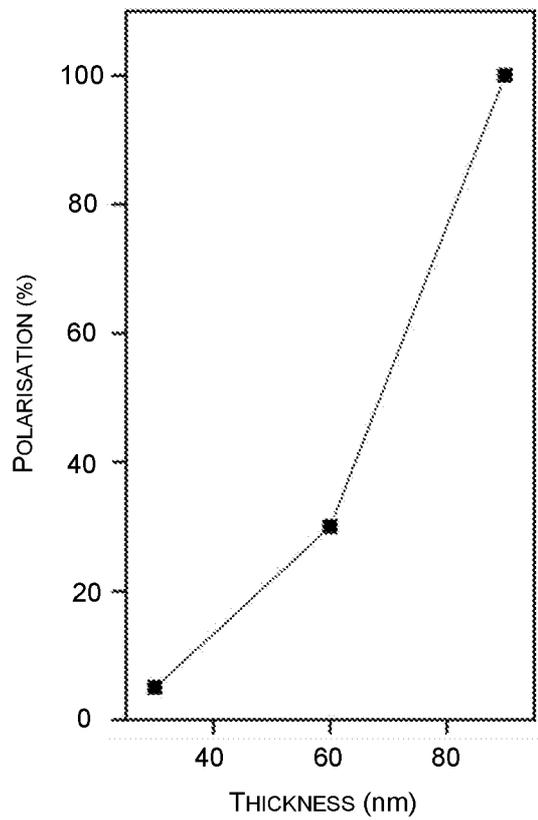


FIG. 5B

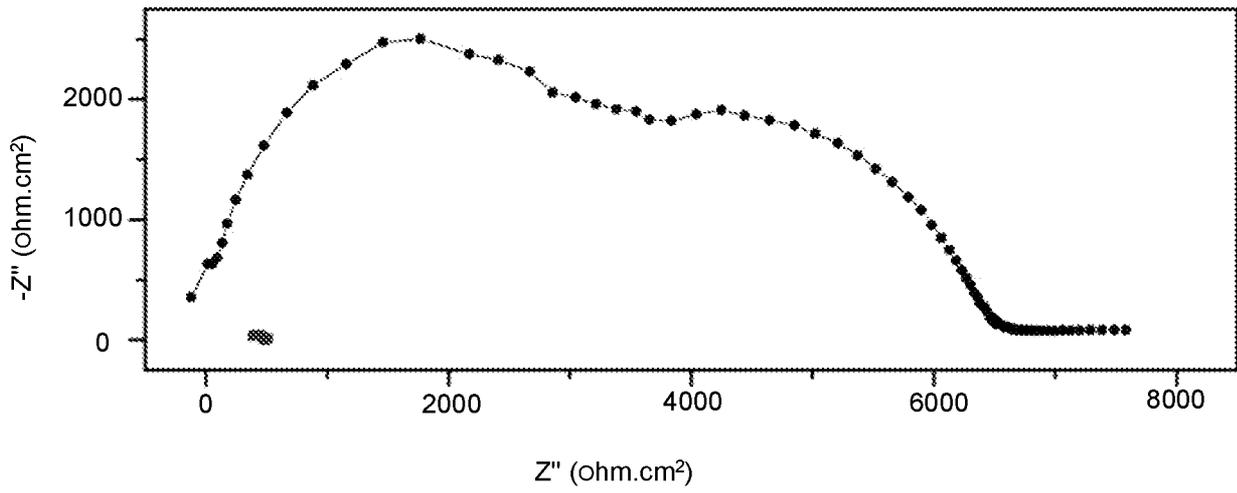


FIG. 6A

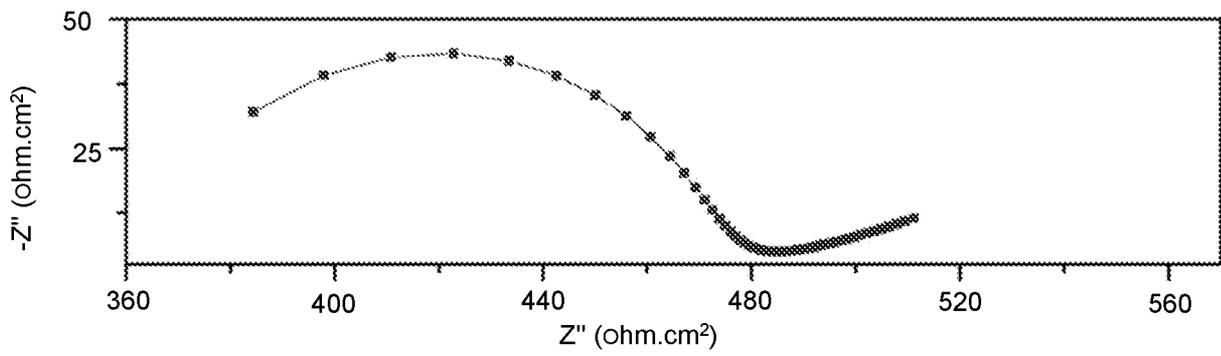


FIG. 6B

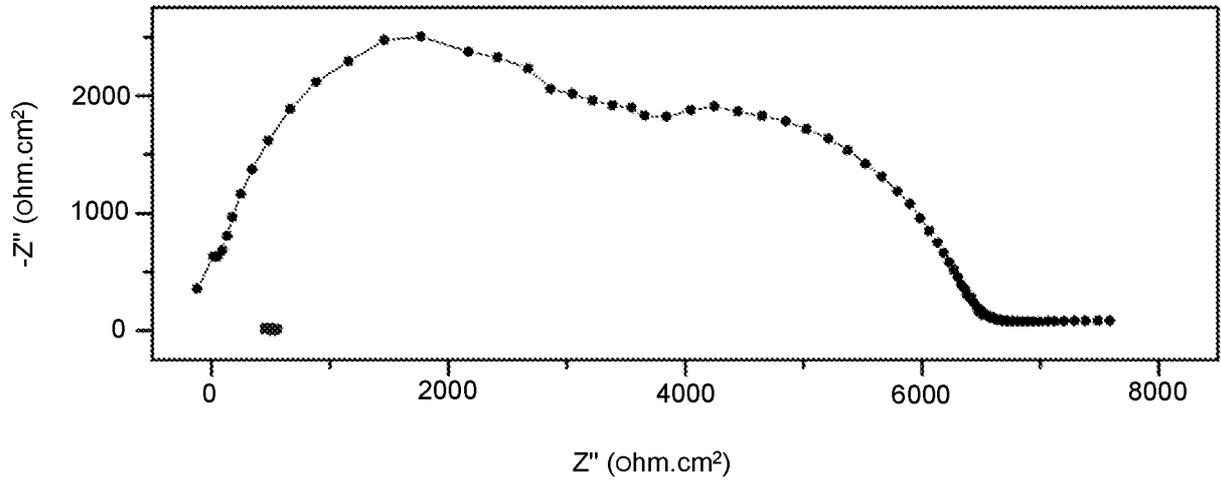


FIG. 7A

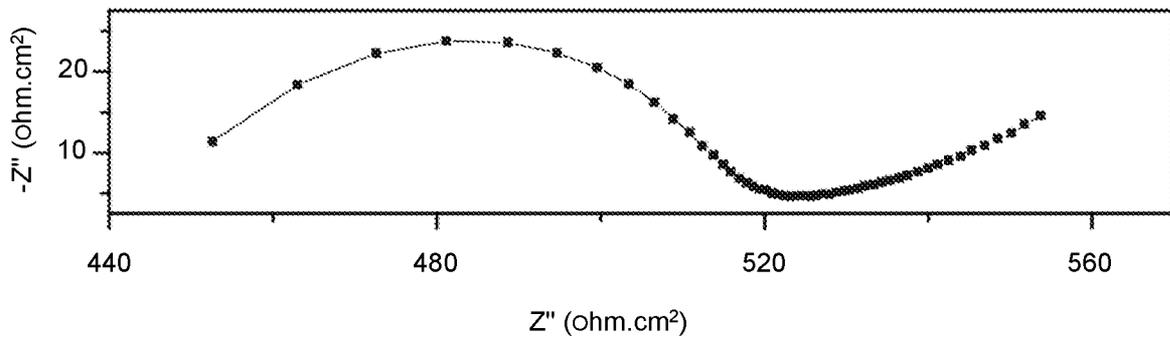


FIG. 7B

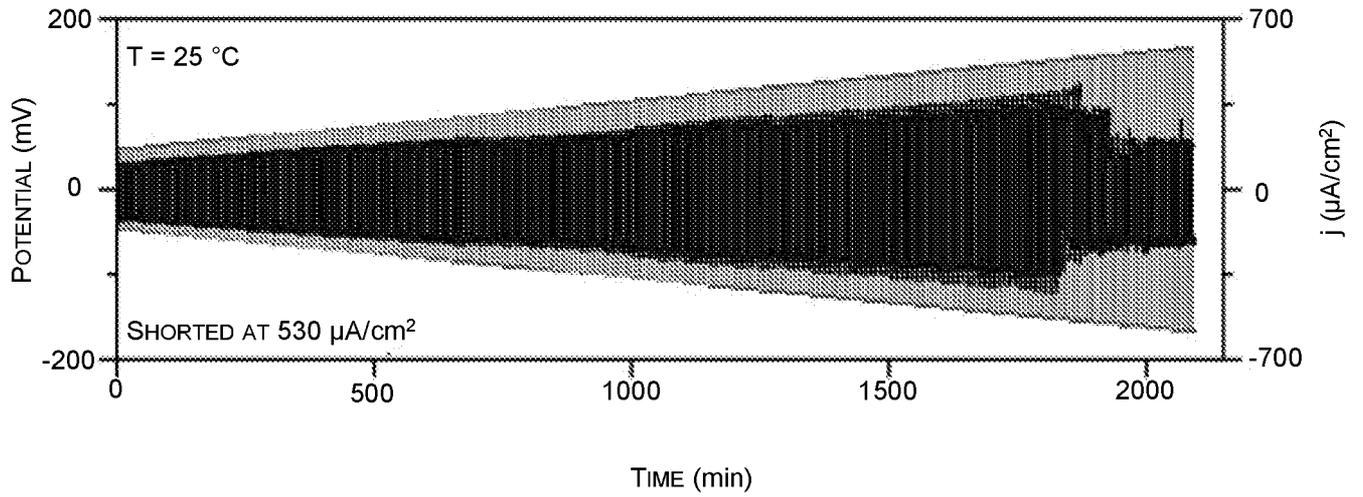


FIG. 8A

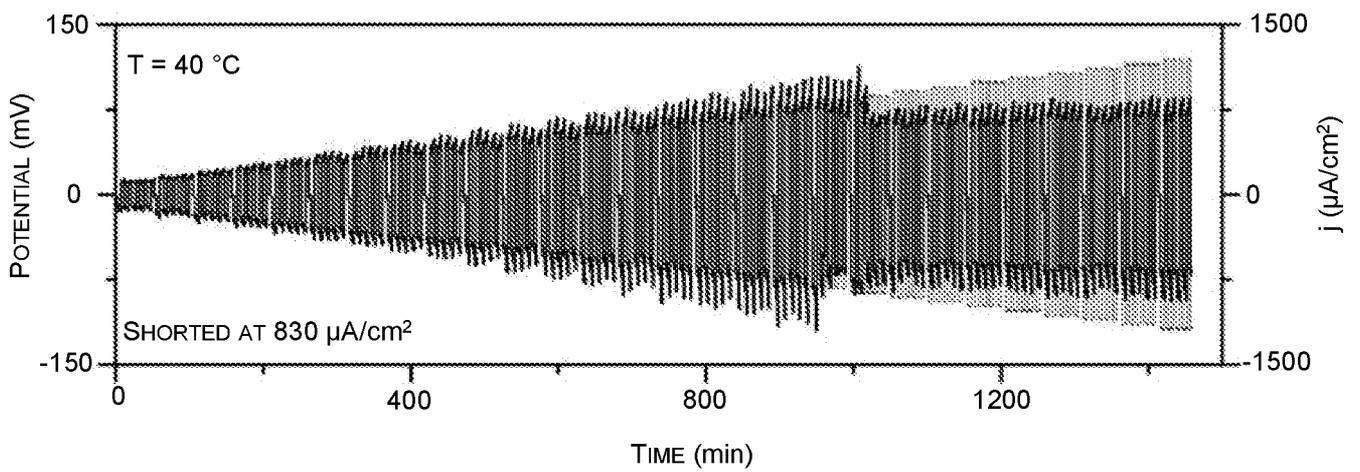


FIG. 8B

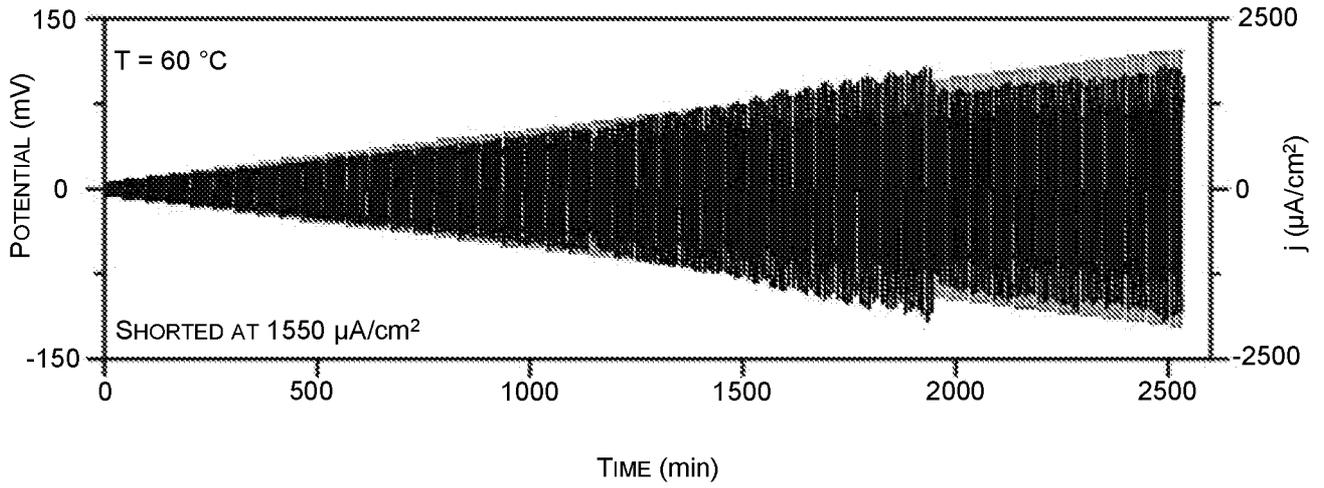


FIG. 8C

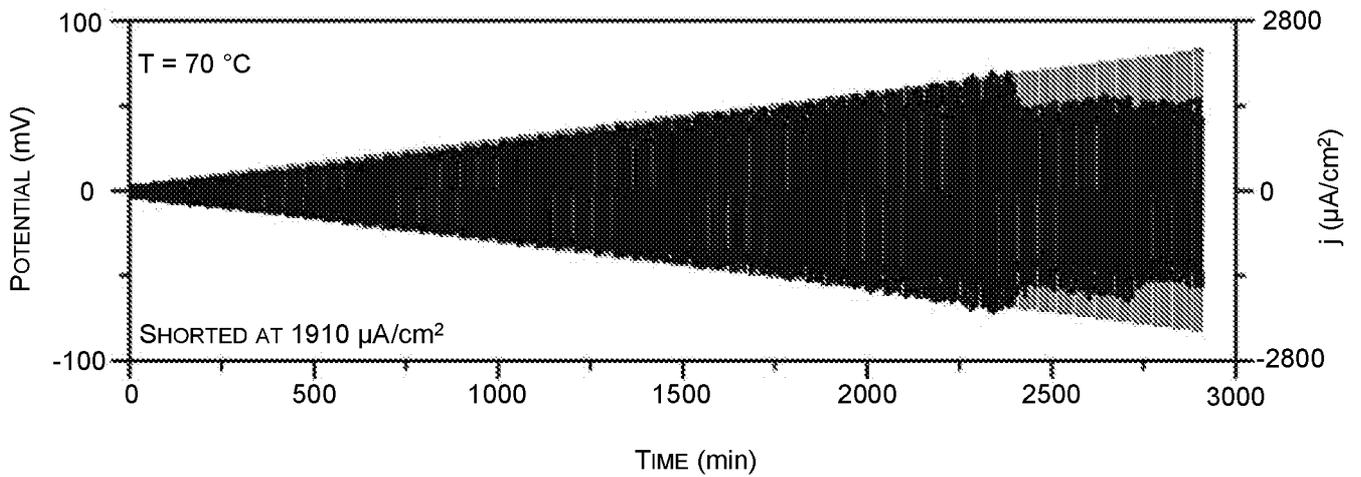


FIG. 8D

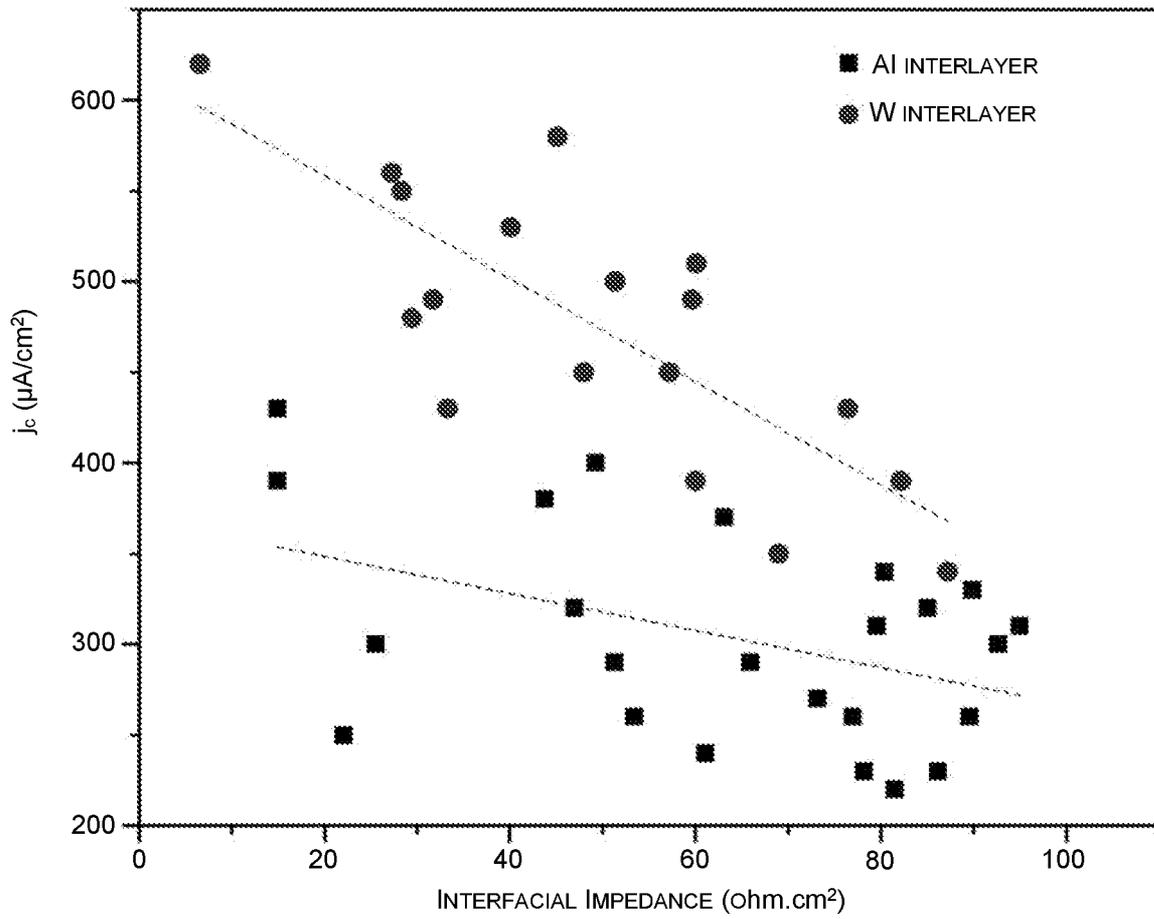


FIG. 9

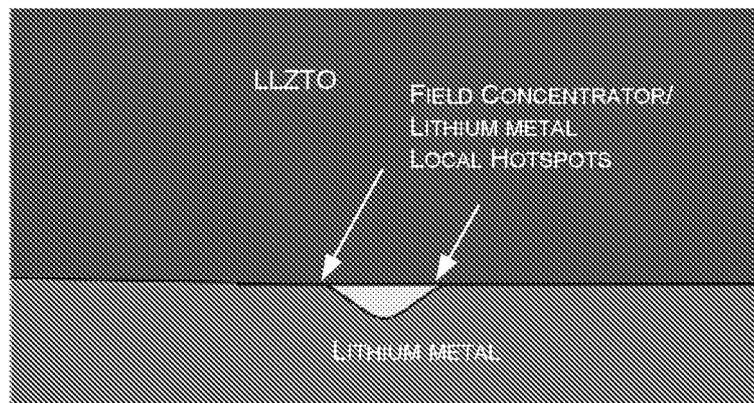


FIG. 10

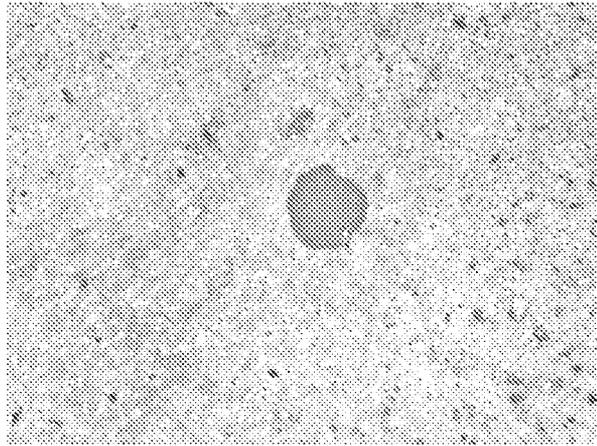


FIG. 11A

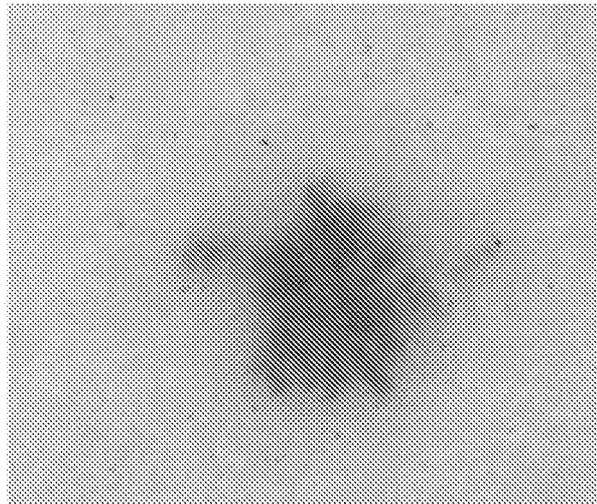


FIG. 11B



FIG. 11C

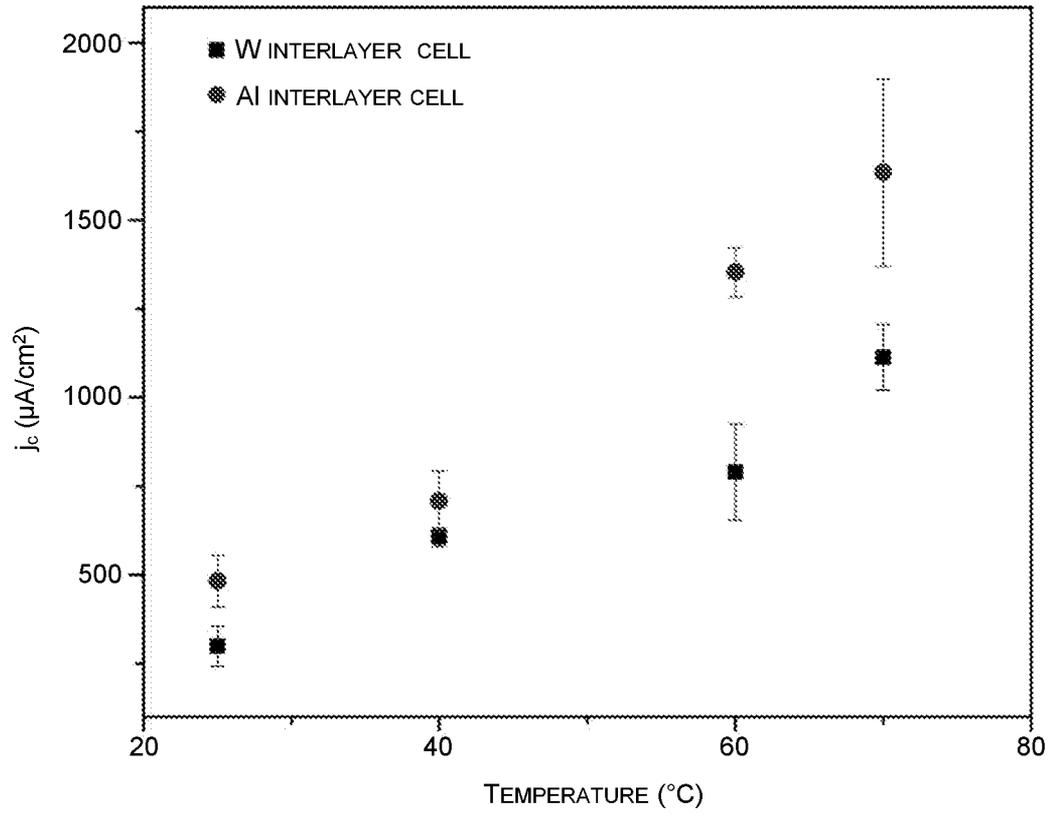


FIG. 12

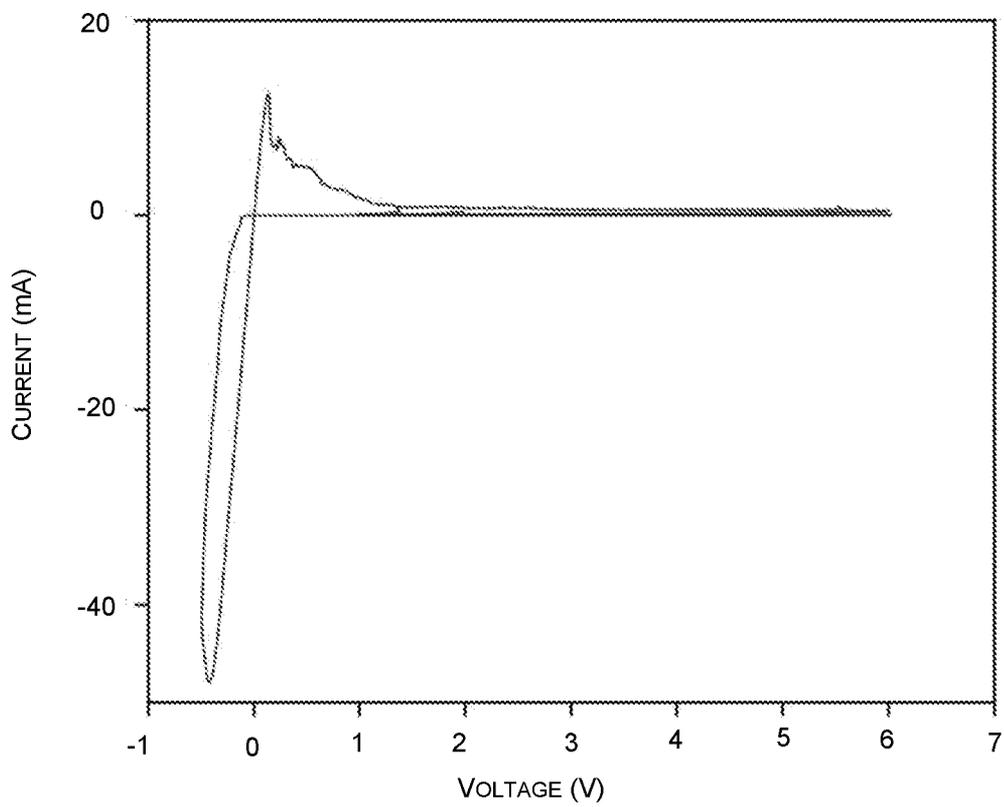


FIG. 13

INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB2020/058463

A. CLASSIFICATION OF SUBJECT MATTER H01M10/0562, H01M10/0525, H01M4/04 Version=2020.01				
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) DATABASES: TotalPatent One, IPO Internal Database KEYWORDS: SOLID, ELECTROLYTE, INTERLAYER, INTERFACIAL, LAYER, REFRACTORY				
C. DOCUMENTS CONSIDERED TO BE RELEVANT				
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.		
Y	US20170338522A1 (UNIVERSITY OF MARYLAND, COLLEGE PARK) 23 NOVEMBER 2017 (23-11-2017) figures 7,9, paragraphs 0009,0011	1-18		
Y	Yan, K. et. al., "Selective deposition and stable encapsulation of lithium through heterogeneous seeded growth" 22 FEBRUARY 2016 (22-02-2016) Abstract, figure 1, pages 1,2	1-18		
Y	US20170346060A1 (Polyplus Battery Co Inc) 30 NOVEMBER 2017 (30-11-2017) Paragraphs 0037,0038	8,16		
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.				
* Special categories of cited documents: <table border="0" style="width: 100%;"> <tr> <td style="width: 50%; vertical-align: top;"> "A" document defining the general state of the art which is not considered to be of particular relevance "D" document cited by the applicant in the international application "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed </td> <td style="width: 50%; vertical-align: top;"> "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family </td> </tr> </table>			"A" document defining the general state of the art which is not considered to be of particular relevance "D" document cited by the applicant in the international application "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family
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Date of the actual completion of the international search 11-12-2020		Date of mailing of the international search report 11-12-2020		
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IB2020/058463

Citation	Pub.Date	Family	Pub.Date
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		EP 3213359 A4	23-05-2018
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