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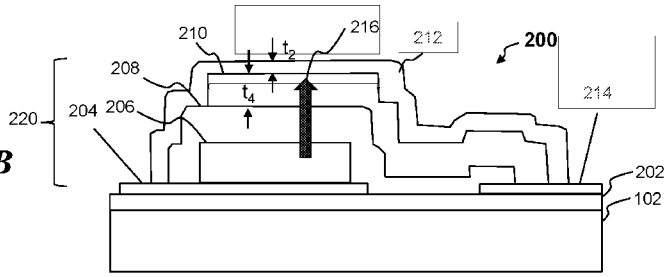


FIG. 2B

(57) Abstract: A thin film device, comprising: an active device region, the active device region having reversible motion at least along a first direction between a first device state and a second device state; and a thin film encapsulant disposed adjacent the selective expansion region, wherein the thin film encapsulant comprises a first thickness in the first device state and a second thickness in the second device state, the first thickness being greater than the second thickness by 10% or greater, wherein the thin film encapsulant comprises a laser-etchable material.

WO 2017/180941 A1

THIN FILM DEVICE ENCAPSULATION VOLUME CHANGE ACCOMMODATING MATERIALS

Related Applications

[0001] This Application claims priority to U.S. provisional patent application no. 62/322,415, filed April 14, 2016, entitled Volume Change Accommodating TFE Materials, and incorporated by reference herein in its entirety.

Field

[0002] The present embodiments relate to thin film encapsulation (TFE) technology used to protect active devices, and more particularly to encapsulating electrochemical devices.

Background

[0003] Thin film encapsulation technology is often employed in devices where the devices are purely electrical devices or electro-optical devices, such as Organic Light Emitting Diodes (OLED). Other than possibly experiencing a generally small global thermal expansion from heat generation during the device operation, these electrical devices and electro-optical devices do not exhibit volume changes during operation, since just electrons and photons are transported within the devices during operation. Such global effects due to global thermal expansion of a device may affect in a similar fashion every component of a given device including the thin film encapsulant, and thus, may not lead to significant internal stress. In this manner, the functionality of the thin film encapsulant in a purely electrical device or electro-optic device is not generally susceptible to stresses from non-uniform expansion during operation.

[0004] Notably, in an electrochemical device ("chemical" portion), matter such as elements, ions, or other chemical species having a physical volume (the physical volume of

electrons may be considered to be approximately zero) are transported within the device during operation with physical volume move. For known electrochemical devices, *e.g.*, a lithium thin film battery (LiTFB) based upon lithium (Li), Li is transported from one side to the other side of a battery as electrons are transported in an external circuit connected to the LiTFB, where the electrons move in an opposite direction to the chemical and elements. One particular example of the volume change experienced by a LiTFB is as follows. When charging a thin film battery having a lithium cobalt oxide ($LiCoO_2$) cathode (~15 μm to 17μm thick $LiCoO_2$), an amount of Li equivalent to several micrometers thick layer, such as 6 micrometers (assuming 100% density), may be transported to the anode when loading is approximately 1 mAhr/cm^2. When Li returns to the cathode side in a discharge process, a comparable volume reduction may result on the anode side (assuming 100% efficiency). The cathode side may also undergo a volume change in an opposite manner, while such changes are much smaller as compared to the anode side.

[0005] As such, known thin film encapsulant structures may be lacking the ability to accommodate such volume change in a robust manner, to ensure the thin film encapsulant continues to provide protection of the electrochemical device during repeated cycling of the device.

[0006] With respect to these and other considerations the present disclosure is provided.

Brief Summary

[0007] In one embodiment, a thin film device may include an active device region, the active device region having reversible motion at least along a first direction between a first device state and a second device state. The thin film device may also include a thin film encapsulant disposed adjacent the selective expansion region, wherein the thin film encapsulant comprises a first thickness in the first device state and a second thickness in the second device state. The first

thickness may be greater than the second thickness by 10% or greater, wherein the thin film encapsulant comprises a laser-etchable material.

[0008] In another embodiment, a thin film battery may include a cathode region comprising a diffusant; an anode, wherein transport of the diffusant takes place between the cathode region to and the anode; and a thin film encapsulant disposed adjacent the anode. The thin film encapsulant may include a first thickness in a first device state and a second thickness in a second device state, the first thickness being greater than the second thickness by 10% or greater, wherein the thin film encapsulant comprises a laser-etchable material.

Brief Description of the Drawings

[0009] **FIG. 1A** illustrates a thin film device according to various embodiments of the disclosure;

[0010] **FIG. 1B** shows a second instance for operation of the thin film device of FIG. 1A;

[0011] **FIG. 1C** provides one embodiment of a thin film encapsulant, arranged as a dyad, according to embodiments of the disclosure; and

[0012] **FIG. 2A** and **FIG. 2B** illustrate views of a thin film battery according to various embodiments of the disclosure.

Detailed Description

[0013] The present embodiments will now be described more fully hereinafter with reference to the accompanying drawings, where some embodiments are shown. The subject matter of the present disclosure may be embodied in many different forms and are not to be construed as limited to the embodiments set forth herein. These embodiments are provided so this disclosure will be thorough and complete, and will fully convey the scope of the subject matter to those skilled in the art. In the drawings, like numbers refer to like elements throughout.

[0014] The present embodiments are related to thin film encapsulant materials and processes, where a thin film encapsulant is used to minimize ambient exposure of active devices. The present embodiments provide novel structures and materials combinations for thin film encapsulants. In various embodiments a thin film encapsulant may be provided to encapsulate active device regions where motion takes place within the active device region during operation. The thin film encapsulant and the active device region may be referred to herein as a "device." In addition, the active device region may constitute an active device as detailed below. The motion within an active device region of the overall device may extend up to serval micrometers, for example. Examples of active devices forming all or part of the active device region include piezoelectric devices, shape memory alloy devices, MEMS device, as well as electrochemical devices such as thin film batteries wherein the active component materials are highly sensitive/reactive to moisture or other ambient materials. To this end, known electrochemical devices such as thin film batteries may be provided with encapsulation to protect the active component materials. The present embodiments also address a problem encountered in devices such as thin film batteries, where a large physical volume change (expansion and contraction) may take place during the operation of the device. More particularly, as noted, volume changes in a device such as a Li thin film battery may take place in a localized or non-uniform manner in a "selective expansion" region, such as an anode. Various embodiments of the disclosure provide appropriate structures and appropriate thin film encapsulant materials and methods of applying such materials in a device, such as a thin film battery, resulting in device structures meeting stringent thin film encapsulant requirements. The present embodiments may also provide structures and materials in a thin film encapsulant serving a combination of other functions. These other functions may include providing improved planarization capability, chemical stability when

in contact with diffusant species such as Li, and adequate absorption of laser irradiation over given wavelengths, to provide maskless patternability.

[0015] In various embodiments, a device such as a thin film device, is provided with a novel thin film encapsulant region (or, simply, "thin film encapsulant"). As noted, the device may be a piezoelectric device, shape memory alloy device, MEMS device in some embodiments. In other embodiments, the film device may be a thin film battery or electrochromic window. In these embodiments, the active device region may exhibit reversible motion at least along a first direction between a first device state and a second device state, where motion takes place over a scale of tenths of micrometers or up to several micrometers. The embodiments are not limited in this context. The reversible motion may take place in a plurality of cycles, such as tens of cycles, hundreds of cycles, thousands of cycles, millions of cycles, and so forth.

[0016] In embodiments where active device is an electrochemical device such as a thin film battery, the active device region may include a source region comprising a diffusant, as well as a selective expansion region, wherein transport of the diffusant takes place from the source region to the selective expansion region. According to various embodiments, the transport of diffusant may take place reversibly between the source region and the selective expansion region. In embodiments where the thin film device is a Li thin film battery, a cathode, such as a solid state cathode, may act as the source region and may include a material such as $LiCoO_2$ or similar material. In embodiments of a Li thin film battery, an anode may act as a selective expansion region, where a large volume change takes place selectively in the selective expansion region, as opposed to other regions in the thin film device.

[0017] To accommodate changes in volume in a selective expansion region, various embodiments provide materials and/or structures in a thin film encapsulant, where the thin film

encapsulant is effective to accommodate volume expansion and contraction in the selective expansion region, rendering a more robust thin film device.

[0018] According to various embodiments, the thin film encapsulant may include at least one layer and may encapsulate at least portions of the source region and selective expansion region. In various embodiments, the thin film encapsulant, at least in a portion adjacent the selective expansion region, may reversibly vary thickness from a first thickness to a second thickness to accommodate changes in volume or thickness of materials in the selective expansion region. For example, in a thin film battery where an anode or a portion of an anode may constitute a selective expansion region, as a result of lithium migration, the anode may change in thickness by several micrometers between a charged state and a discharged state in the thin film battery. In the present embodiments, the thin film encapsulant may expand or contract in thickness to accommodate for the increase or decrease in anode thickness, resulting in less stress, less mechanical failure, and better protection of the active device of a thin film device. Depending upon the thickness of the thin film encapsulant, the change in thickness between a first thickness in a charged state and a second thickness in discharged state may be as follows. The first thickness may be greater than the second thickness by 5% or more, and in some examples, the first thickness is greater than the second thickness by 10% or more. The embodiments are not limited in this context.

[0019] According to various embodiments, the thin film encapsulant may include at least one layer comprising a laser-etchable material and in particular a material etchable according to laser ablation or similar process. In a thin film encapsulant containing a laser-etchable material, electromagnetic radiation of a given wavelength of a laser beam is highly absorbed in the thin film encapsulant. Examples of suitable radiation wavelengths include the range from 157 nm to 1064 nm. For example, for a laser beam having a wavelength in the visible range, a transparent or

completely clear-appearing polymer layer may not be highly absorbent of the electromagnetic radiation of the laser beam. For the same laser beam having wavelength in the visible range, an opaque, black, or translucent polymer layer may be highly absorbent of the electromagnetic radiation, and may accordingly be deemed a laser-etchable material. The embodiments are not limited in this context. In this manner, a patterned thin film device such as a thin film battery may be formed, where the active device portions of the thin film battery as well as a volume-change-accommodating encapsulant can be patterned using a maskless process. A useful maskless process includes laser patterning, suitable to define the final device structure including the thin film encapsulant.

[0020] Turning now to **FIG. 1A** there is shown a thin film device 100 according to embodiments of the disclosure. The thin film device 100 may constitute an electrochemical device such as a thin film battery, electrochromic window, or other electrochemical device. In the embodiment of FIG. 1A, the thin film device 100 may include a substrate 102 and a source region 104 disposed on the substrate 102. In various embodiments the source region 104 may represent a cathode of a thin film device such as a thin film battery. The source region 104 may act as a source of a diffusant such as lithium, where the diffusant may reversibly diffuse from the source region 104 and into the source region 104. The thin film device 100 may also include an intermediate region 106 disposed on the source region, and a selective expansion region 108 disposed on the intermediate region 106. The selective expansion region 108 may be an anode, for example, of a thin film device. In the instance shown in FIG. 1A, the thin film device 100 may represent a thin film battery in a discharged state where the battery is not charged so charge species such as lithium are depleted from the anode. In this example, the selective expansion region 108

remains relatively contracted, while the thin film encapsulant 110 is relatively expanded or relaxed, as represented by the first thickness, t_1, along the X-axis of the Cartesian coordinate system shown.

[0021] Turning now to **FIG. 1B** there is shown a second instance for operation of the thin film device 100, representing, for example, a second device state of the thin film device 100. In the instance shown in FIG. 1B, the thin film device 100 may represent a thin film battery in a charged state. In the charged state the battery may be charged by outdiffusion of a diffusant such as lithium from the source region 104 and the transporting of the diffusant across intermediate region 106 to accumulate at an anode, represented by the selective expansion region 108. Accordingly, the selective expansion region 108 may be expanded with respect to the state of FIG. 1A, while the thin film encapsulant is relatively compressed as represented by a second thickness t_2. According to various embodiments, the change in thickness of the selective expansion region 108 from a third thickness, t_3, in the discharged state of FIG. 1A to a fourth thickness, t_4, in the charged state of FIG. 1B may displace the thin film encapsulant 110. The displacement of thin film encapsulant 110 may take place at least in a region 114, where the region 114 is adjacent the selective expansion region 108. Accordingly, the thin film encapsulant 110 may accommodate the expansion of the selective expansion region 108 by a reduction in thickness of the thin film encapsulant 110 from the first thickness, t_1, as represented by the discharged state of FIG. 1A to the second thickness, t_2, as shown in the charged state of FIG. 1B. Accordingly, the thin film encapsulant 110 may be vertically stretched at the battery cell edges.

[0022] In some embodiments the thin film encapsulant 110 includes a polymer stack (not separately shown in FIG 1A) including at least one polymer layer and a permeation blocking layer, such as a rigid dielectric layer or a metal layer. In variants of such embodiments, the individual thicknesses (t_1, t_2, t_3 and t_4) may change during cycling. At the same time, the thickness of the at

least one polymer layer of thin film encapsulant 110 may be sufficiently large and the polymer layer sufficiently pliable, so as to accommodate the expansion and the contraction taking place during cycling in the following manner. During cycling, where t_1 and t_2 may represent opposite extremes of thickness, the thickness and pliability of the polymer layer may be such where the sum of the first thickness and third thickness differs by 10% or less from a sum of the second thickness and fourth thickness, as defined above. This relationship may be expressed symbolically where the thickness sum of $t_2 + t_4$ is not substantially different from the thickness sum of $t_1 + t_3$, such as a difference of less than 10 %; and in some cases the thickness sum of $t_2 + t_4$ differs from the thickness sum of $t_1 + t_3$ by less than 5 %. In this manner, the pressure on the permeation blocking layer of the thin film encapsulant 110 is minimized. As noted above, in known batteries an amount of Li equivalent to several micrometers thick layer, such as 6 micrometers (assuming 100% density), may be transported to an anode. Accordingly, various embodiments of a thin film encapsulant 110 may accommodate expansion and contraction on the order of at least one micrometer, and in some cases, several micrometers, such as 6 micrometers or more. In particular, this accommodation of thickness changes up to 6 micrometers or more may be such where the thickness sum of $t_2 + t_4$ does not substantially vary from the thickness sum of $t_1 + t_3$, such as a difference of less than 10 %.

[0023] In various embodiments, the thin film encapsulant 110 may have an elongation property of at least 5%. In particular embodiments, the elongation to break may be 70% or greater for at least one polymer layer of the thin film encapsulant.

[0024] According to various embodiments, the thin film encapsulant 110 may include a polymer layer having a thickness of 10 μm to 50 μm, and the selective expansion region 108 may constitute an anode. The anode thickness may change by at least 1 μm between a charged state

and a discharged state. In specific embodiments, the polymer layer of the thin film encapsulant 110 may constitute a polymer layer stack including multiple sub-layers of different polymers, where at least one sub-layer is soft and pliable. By proper choice of the thickness of thin film encapsulant and the materials for a thin film encapsulant, the thin film encapsulant 110 may have adequate flexibility to accommodate expansion and contraction of at least 1 μm when the thin film device 100 is cycled between states, such as a charged state and discharged state in embodiments of a thin film battery. The accommodation of changes in volume of the selective expansion region 108 may be accomplished in a manner avoiding stress-induced cracking in the encapsulant materials, as well as delamination or other degradation, where such degradation may compromise the integrity of the thin film device being protected.

[0025] According to various embodiments of the disclosure a thin film encapsulant may be formed from a multilayer stack, where the multilayer stack includes at least one polymer layer. In specific embodiments, a given polymer "layer" is arranged as a polymer layer stack having a plurality of polymer sub-layers as described above. In particular embodiments, the thin film encapsulant 110 may include a getter/absorbent infused polymer material, a porous low dielectric constant material, an epoxy, a printed circuit board material, a photo-resist material, or a silver paste, and combinations thereof. In addition to the aforementioned materials, particular examples of suitable polymer materials include silicone, rubber, urethane, polyurethane, polyurea, polytetrafluoroethylene (PTFE), parylene, polypropylene, polystyrene, polyimide, nylon, acetal, ultem, acrylic, epoxy, and phenolic polymers. The embodiments are not limited in this context.

[0026] In various embodiments, the thin film encapsulant 110 may be arranged with a dyad, where a given dyad includes a polymer layer and a rigid moisture barrier layer such as a dielectric layer or a metal layer, or combinations of metal layer and dielectric layer. The dyad may

act as a "functional dyad" where at least one layer of the functional dyad provides a diffusion barrier to contaminants such as moisture; and at least one layer includes a soft and pliable layer for accommodating changes in dimension of an active device region in a reversible manner. A suitable metal layer may include Cu, Al, Pt, Au, or other metal. A rigid dielectric layer may be composed of a known material such as silicon nitride where the rigid dielectric layer has a combination of relatively high elastic modulus and hardness, for example. In the case of silicon nitride, the Vicker's hardness is ~ 13 GPa, and Young's Modulus is ~ 43500 Kpsi or ~ 300 GPa). Accordingly, the rigid dielectric layer is less pliable than the polymer layer (*e.g.*, exemplary mechanical properties of polymer layers include silicone: hardness of ~ A40 Shore A, Young's Modulus of ~ 0.9 Kpsi or ~ 6.2 MPa; Parylene-C: hardness of ~ Rockwell R80, Young's Modulus of ~ 400 Kpsi or ~ 2.8 GPa; KMPR: Young's Modulus of ~ 1015 Kpsi or ~ 7.0 GPa; polyimide: hardness of D87 Shore D, Young's Modulus of ~ 2500 Kpsi or ~ 17.2 GPa). Other examples of appropriate rigid dielectric materials include sputtered dielectric materials (*i.e.* sputtered Pyrex or similar borosilicate material), low temperature spin-on or powder coated dielectric or glaze coatings (processed with or without surface Rapid Thermal Processing to improve barrier properties).

[0027] As used herein, a "soft and pliable" material may refer to a material having an elastic (Young's) modulus less than 20 GPa, for example, while a "rigid material" such as a rigid metal or rigid dielectric may have an elastic modulus greater than 20 GPa. Other characteristic properties associated with a soft and pliable material include a relatively high elongation to break, such as 70% or greater for at least one polymer layer of the thin film encapsulant. In some examples, such as silicone, a soft and pliable material may have an elongation to break up to 200% or greater.

[0028] The dielectric breakdown voltage of a rigid dielectric layer may exceed 4 MV/cm in some examples. The high dielectric breakdown strength may in general be an indication of high electrical resistivity. For rigid dielectrics (and polymers) in a battery of the present embodiments, a high electrical resistivity, as indicated by the high dielectric breakdown voltage, prevents shorting from anode current collector or cathode current collector through the thin film encapsulant.

[0029] In some embodiments, the thin film encapsulant may be arranged having a plurality of dyads. **FIG. 1C** provides one embodiment of a thin film encapsulant 110, arranged as a dyad. The dyad may include a polymer layer 120 and a rigid dielectric layer 122, where the rigid dielectric layer 122 may be Si_3N_4, $Al2O_3$, ytrria stabilized zirconia (YSZ), ZrO_2, SiO_2, SiO_xN_y, to name a few materials. In other embodiments, the rigid dielectric layer 122 may instead by a rigid metal layer. An advantage of a rigid metal layer is the rigid metal layer may provide strength while being less brittle than a rigid dielectric layer.

[0030] Configurations where a polymer layer such as polymer layer 120 is a polymer layer stack including multiple polymer sub-layers may provide advantages over configurations having just one polymer layer. For example, a three-layer polymer layer stack may have an inner polymer layer exhibiting soft and pliable properties and outer polymer layers, where the outer polymer layers are harder and function to distribute stress more uniformly. The harder polymer layers may accordingly reduce localized abnormally high stress points, where such stress points would otherwise cause puncturing of the rigid dielectric layer 122, for example.

[0031] Turning now to **FIG. 2A** and **FIG. 2B** there are shown views of a thin film battery 200 according to various embodiments of the disclosure. The thin film battery 200 may include a substrate 102, intermediate layer 202, a cathode current collector 204, a cathode 206, a solid state electrolyte 208, an anode 210, a thin film encapsulant 212, and an anode current

collector 214, as shown. In some examples, the intermediate layer 202 may function as a bi-directional diffusion barrier layer between substrate 102 and the stack of layers above substrate 102, and may function as an "adhesion promotion layer." In one embodiment the intermediate layer 202 may be composed of Al_2O_3 and titanium. In some embodiments, a cathode current collector 204, cathode 206, solid state electrolyte 208, anode 210, and anode current collector 214 may be composed of known materials. For example, the cathode current collector 204 may be a known metal material, the cathode may be $LiCoO_2$ or similar material, the solid state electrolyte 208 may be a lithium phosphorus oxynitride (LiPON), the anode 210 may include lithium or lithium-containing material. The anode current collector 214 may include a metal such as copper, may be copper plated with lithium, or another known anode current collector. The embodiments are not limited in this context. The thin film encapsulant 212 may be a material or set of materials as discussed above.

[0032] As shown in FIG. 2A, the thin film battery 200 may have a co-planar structure where cathode current collector 204 and anode current collector 214 are arranged in a coplanar fashion. In other embodiments the cathode current collector 204 and anode current collector 214 may be arranged in a non-coplanar fashion, for example, where the anode current collector 214 is arranged in a plane above the cathode current collector. As illustrated, the thin film encapsulant 212 encapsulates the cathode 206, solid state electrolyte 208, and anode 210. During operation, the thin film encapsulant 212 protects these components from attack from water vapor or other ambient material. When the thin film battery 200 is cycled between a charged state (FIG. 2B, where diffusant 216 diffuses to the anode 210) and discharged state (FIG. 2A, where the diffusant 216 diffuses to the cathode 206), the thin film encapsulant 212 may elastically deform. In particular embodiments, the thin film encapsulant 212 may elastically deform in a manner to

accommodate the changes in thickness of the anode 210, as generally described above with respect to FIG. 1A and FIG. 1B.

[0033] As additionally shown in FIG. 2A and FIG. 2B various components of thin film battery 200 formed on the substrate 102 may form a layer stack 220, where the layer stack 220 is patterned so as to form a discrete battery. The layer stack 220 may be formed by depositing the different layers and subsequently patterning these layers to form the thin film battery 200 as shown.

[0034] In various embodiments, at least the thin film encapsulant 212 may be patterned by a laser etching process, in particular by a maskless laser process, such as laser ablation. The material(s) of the thin film encapsulant 212, including individual polymer layers, as well as any rigid dielectric or metal layers, such as a rigid metal layer, may be designed to absorb the electromagnetic radiation of a given laser used to perform laser ablation. In some embodiments, having a laser wavelength in the high energy range (i.e. green, UV, deep UV) is useful to provide good layer-by-layer material ablation control. Hence, a thin film encapsulant material having good light absorption properties in these laser wavelengths may be patterned more effectively. Providing coloration in a thin film encapsulant material is useful to enable laser beam absorption. For example, magenta coloring of a thin film encapsulant will work well in conjunction with the use of green lasers since green light absorption is maximized for this color. Black coloring also works well for thin film encapsulant coloring. Also, dyes and pigments for use as thin film encapsulant material coloring material may be selected so as not to have chemical reactivity with battery cell materials of interest.

[0035] While in some of the aforementioned embodiments suitable radiation wavelengths may include the range from 266 nm to 1064 nm, in other embodiments excimer laser radiation may be used to pattern at least the thin film encapsulant part of a device. In this case the optical

properties of materials such as polymers in the thin film encapsulant may include a layer absorbent to laser radiation at a wavelength in a range of 157 nm to 1064 nm. In particular, the thin film encapsulant may be tuned to be highly absorbent at the wavelength of a given excimer laser, such as ~ 157nm, 172nm, 193nm, 248nm, 1064 nm. Accordingly, radiation wavelengths useful for patterning a thin film encapsulant in the present embodiments may extend between 157 nm to 1064 nm. As disclosed herein above, a thin film encapsulant may be formed for a thin film device where the structure and materials of the thin film encapsulant accommodate selective volume changes taking place within certain regions (a "selective expansion region") of the thin film device. The selective volume changes may be reversible volume changes where a component such as an anode increases in thickness and decreases in thickness. The materials of the thin film encapsulant may be tailored so a maskless process, such as laser ablation may be used to pattern the thin film devices. In this manner, electrochemical device structures able to accommodate volume expansion during cycling between different states may be conveniently be formed using a combination of deposition processes and maskless patterning.

[0036] There are multiple advantages provided by the present embodiments, including the ability to reduce the amount of non-active packaging materials used in a thin film device, leading to enhanced energy density of these devices, as well as the further advantage of the ability to conveniently form a thin film device using maskless patterning of the thin film encapsulant.

[0037] The present disclosure is not to be limited in scope by the specific embodiments described herein. Indeed, other various embodiments of and modifications to the present disclosure, in addition to those described herein, will be apparent to those of ordinary skill in the art from the foregoing description and accompanying drawings. Thus, such other embodiments and modifications are intended to fall within the scope of the present disclosure. Furthermore, the

present disclosure has been described herein in the context of a particular implementation in a particular environment for a particular purpose, while those of ordinary skill in the art will recognize the usefulness is not limited thereto and the present disclosure may be beneficially implemented in any number of environments for any number of purposes. Thus, the claims set forth below are to be construed in view of the full breadth and spirit of the present disclosure as described herein.

What is claimed is:

1. A thin film device, comprising:

an active device region, the active device region having reversible motion at least along a first direction between a first device state and a second device state; and

a thin film encapsulant disposed adjacent the active device region, wherein the thin film encapsulant comprises a first thickness in the first device state and a second thickness in the second device state, the first thickness being greater than the second thickness by 10% or greater,

wherein the thin film encapsulant comprises a laser-etchable material.

2. The thin film device of claim 1, wherein the active device region comprises:

a source region comprising a diffusant; and

a selective expansion region, wherein transport of the diffusant takes place from the source region to the selective expansion region.

3. The thin film device of claim 2, wherein the source region comprises a solid state cathode, and wherein the selective expansion region comprises an anode.

4. The thin film device of claim 3, wherein the anode comprises a third thickness in the first device state and a fourth thickness in the second device state, wherein a sum of the first thickness and third thickness differs by 10% or less from a sum of the second thickness and fourth thickness.

5. The thin film device of claim 2, wherein the thin film encapsulant comprises a polymer layer disposed adjacent the selective expansion region.

6. The thin film device of claim 1, wherein the thin film encapsulant comprises a multilayer stack, the multilayer stack including at least one polymer layer.

7. The thin film device of claim 1, the thin film encapsulant comprising at least one of: a getter/absorbent infused silicone, a porous low dielectric constant material, a silver paste, and epoxy, a printed circuit board) material, a photo-resist material, silicone, rubber, urethane, polyurethane, polyurea, polytetrafluoroethylene, parylene, polypropylene, polystyrene, polyimide, nylon, acetal, ultem, acrylic, epoxy, and phenolic a polymer, or combination thereof.

8. The thin film device of claim 1, the thin film encapsulant comprising a plurality of dyads, a dyad comprising a polymer layer and at least one of: a rigid dielectric layer and a metal layer.

9. The thin film device of claim 8, wherein the polymer layer comprises a polymer stack, the polymer stack including a plurality of polymer sub-layers, wherein at least one sub-layer of the plurality of polymer sub-layers

10. The thin film device of claim 2, the thin film device comprising a lithium thin film battery, the active device region comprising a cathode of the lithium thin film battery, the selective expansion region comprising an anode of the lithium thin film battery.

11. The thin film device of claim 10, further comprising a solid state electrolyte disposed between the anode and the cathode, wherein the thin film encapsulant encapsulates the cathode, the anode, and the solid state electrolyte.

12. The thin film device of claim 2, the thin film encapsulant comprising a polymer layer arranged as a polymer layer stack having a thickness of 10 um to 50 um, the selective expansion region comprising an anode, wherein an anode thickness changes by at least 1 um between the first device state and the second device state.

13. A thin film battery, comprising:

a cathode region comprising a diffusant;

an anode, wherein transport of the diffusant takes place between the cathode region and the anode; and

a thin film encapsulant disposed adjacent the anode, wherein the thin film encapsulant comprises a first thickness in a first device state and a second thickness in a second device state, the first thickness being greater than the second thickness by 10% or greater,

wherein the thin film encapsulant comprises a laser-etchable material.

14. The thin film battery of claim 13, wherein the thin film encapsulant comprises a layer absorbent to laser radiation at a wavelength in a range of 157 nm to 1064 nm.

15. The thin film battery of claim 13, wherein the anode comprises a third thickness in the first device state and a fourth thickness in the second device state, wherein a sum of the first thickness and third thickness differs by 10% or less from a sum of the second thickness and fourth thickness.

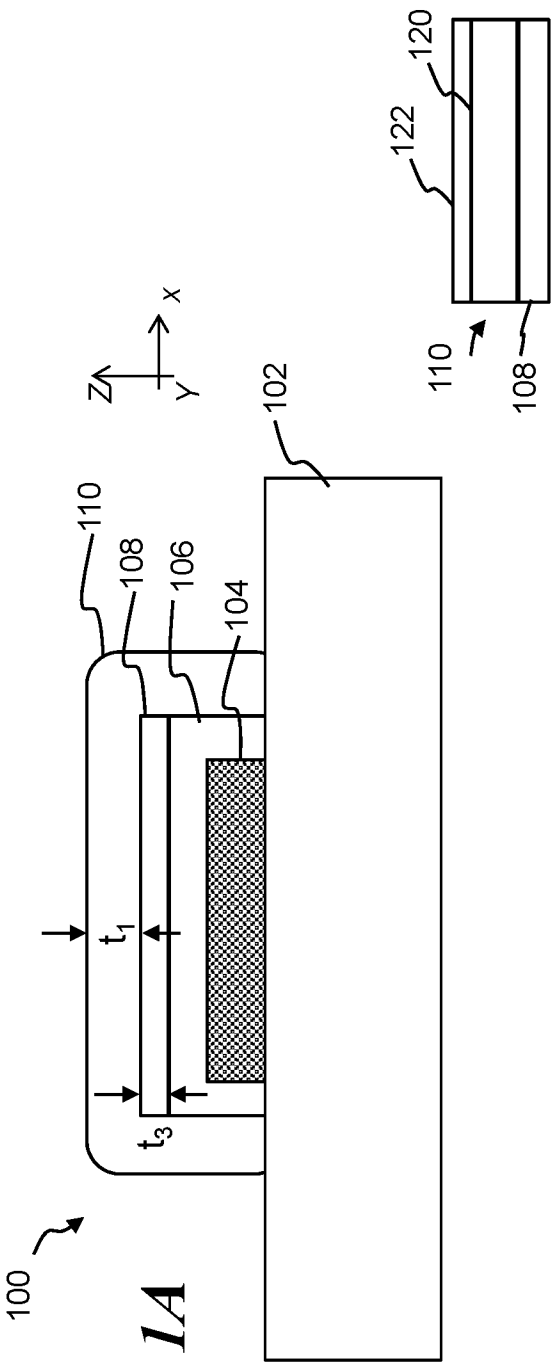


FIG. 1A

FIG. 1C

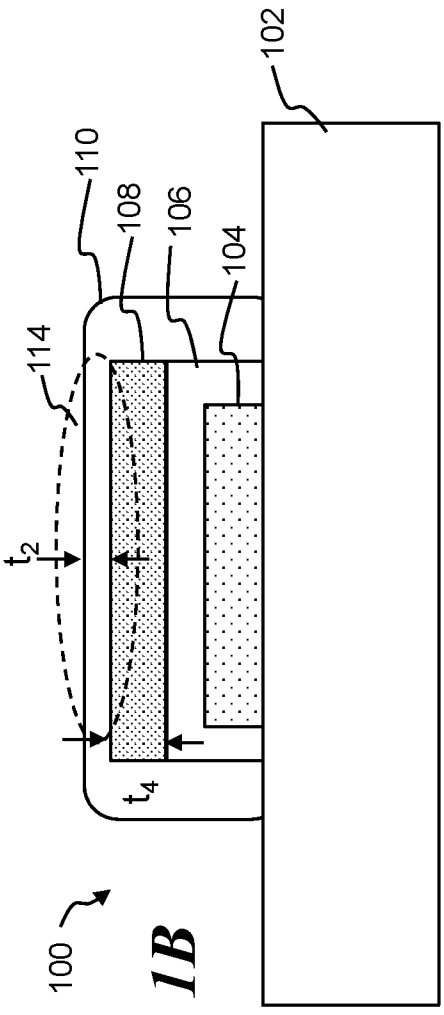
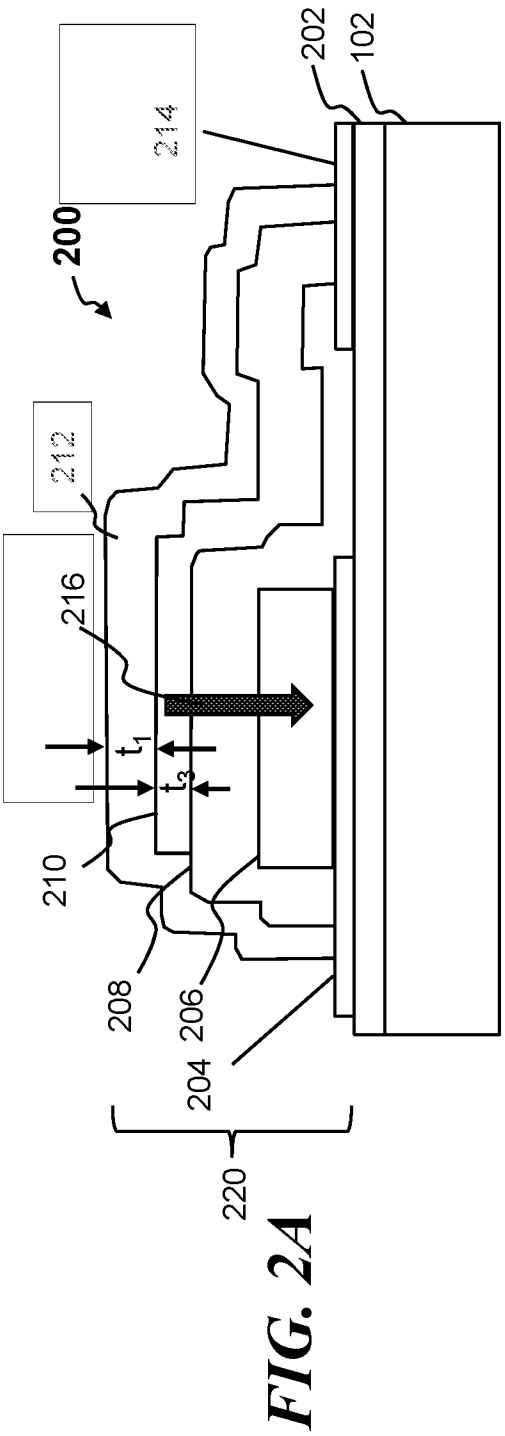


FIG. 1B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212
216
t_1
t_3
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208
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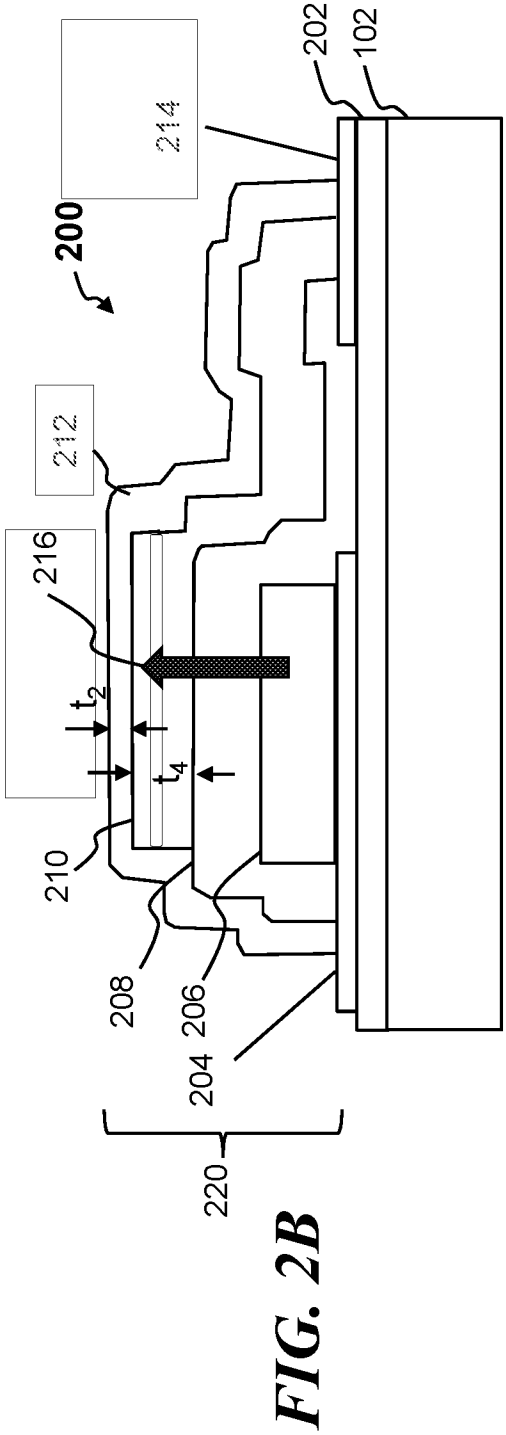
FIG. 2A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t_2
t_4
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204
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FIG. 2B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/027535

A. CLASSIFICATION OF SUBJECT MATTER

H01M 10/04(2006.01)i, H01M 10/0585(2010.01)i, H01M 2/02(2006.01)i, H01M 2/10(2006.01)i, H01M 4/13(2010.01)i, H01M 10/0562(2010.01)i, H01M 10/052(2010.01)i

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 10/04; H01M 2/08; C23C 14/34; H01M 6/40; H01L 29/84; H01M 4/02; H01M 10/00; H01B 1/00; H01L 27/14; H01M 10/0585; H01M 2/02; H01M 2/10; H01M 4/13; H01M 10/0562; H01M 10/052

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: thin film battery, encapsulation layer, lithiation, thickness, volume, expansion, contraction, lithium, internal stress

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2008-0003493 A1 (BATES, JOHN B.) 03 January 2008 See paragraphs [0021]-[0023], [0043]-[0051]; claims 1, 8, 9, 13-15, 17, 19, 20; and figures 1, 4, 5.	1-15
Y	US 2015-0325862 A1 (APPLIED MATERIALS, INC.) 12 November 2015 See paragraphs [0032], [0034], [0043]; and figures 3A-3F, 4A-4D.	1-15
A	US 2009-0181303 A1 (NEUDECKER, BERND J. et al.) 16 July 2009 See paragraphs [0010], [0011], [0116], [0017], [0020], [0024]; claims 1-6, 8-12, 16, 20, 21, 32; and figure 1.	1-15
A	US 6168884 B1 (NEUDECKER, BERND J. et al.) 02 January 2001 See column 3, line 46-column 5, line 5; claims 1, 2, 10, 12; and figures 1A, 1B.	1-15
A	US 7298017 B1 (LIU, PING et al.) 20 November 2007 See the whole document.	1-15

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

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 July 2017 (19.07.2017)	**20 July 2017 (20.07.2017)**

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/US2017/027535

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		WO 00-60689 A9	14/03/2002
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